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On the Eclipses of the Satellites of Saturn in the Years 1904 *and* 1905. By H. Struve.

The cycle of eclipses and other phenomena of the satellites of *Saturn*, which begins in the present year and will extend over the next five years, gives an opportunity for a series of important observations to which the attention of astronomers may be directed. In the first place, the dimensions of the planet can be determined by these observations with considerable precision. At the same time they will lead to interesting conclusions as to the diameters of the satellites and the atmosphere of the planet and the penumbra. Further they will serve to correct the elements of the orbits of the satellites.

In previous periods very few observations of these phenomena have been made. During the last period, beginning with the year 1889, more attention has been directed to them, thanks to the predictions of Mr. Marth. Some observations of eclipses of the brighter satellites which have been published and discussed in the *Monthly Notices*, vol. liv., show the great accuracy of these observations, and the desirability of a more extensive repetition at the next opportunity. For the success of these observations it is important that astronomers should be acquainted with the conditions of the phenomena, particularly the times of the eclipses and the geocentric places of the satellites. During the next years the reappearances taking place after the opposition can be observed with more facility and accuracy than the disappearances before the opposition, as they occur at greater distances from the planet's limb. On the contrary, after 1907, when the Earth

will have passed through the plane of the ring, the disappearances before the opposition are easier to observe.

The following note refers to the eclipses in the next two years. During the opposition of 1904 only the two interior satellites *Mimas* and *Enceladus* will be eclipsed. Whether we might succeed in the observations of eclipses of *Mimas* is very doubtful on account of the faintness of the satellite and the proximity of *Saturn's* disc. But in the case of *Enceladus* it is possible that the eclipses might be observed in *powerful* telescopes. The eclipses of *Enceladus* will begin about three or four months after the opposition, not before November, on the northern side of the planet's disc, and are distinguished by the fact that both the disappearances and reappearances are visible from the Earth. The beginning of the cycle of eclipses changes considerably according to the supposition to be made as to the dimensions of the planet. Assuming the polar semiaxis of the planet at mean distance to be $b_0 = 8''{\cdot}025$, the first eclipse of *Enceladus* will take place on November 19; assuming $b_0 = 7''{\cdot}825$, we find for the first eclipse December 18. The first value corresponds approximately to the dimension of the planet derived by measures with filar micrometers, the smaller value agrees with the result derived from the eclipses of *Rhea*, *Dione*, and *Tethys* in the years 1890–91 (*Monthly Notices*, vol. liv.), and approaches in the same time the mean value of the heliometric measures. Therefore the observation of the superior conjunctions of *Enceladus* in November and December of this year will lead to a more exact determination or at least to a maximum value of the polar diameter. In the following table are given the times of the heliocentric conjunctions, and for every tenth day the geocentric coordinates of *Enceladus*, x, y, referred to the axes of the ring; further, the semi-diameter of the disc b and the semi-duration of the eclipses, on the supposition $b_0 = 8''{\cdot}025$:

Superior Conjunctions of Enceladus, 1904.

Date.	Helioc. Conj. G.M.T.	Geoc. Coord.		Semi-diam.	Semi-duration.
		x	y	b	
1904.	h m	"	"	"	h m
Nov. 10	0 11	+3·1	+9·2	7·8	...
11	9 4				
12	17 58				
14	2 52				
15	11 45				
16	20 39				
18	5 32				
19	14 26	+3·0	+8·9	7·7	0 2
20	23 19				
22	8 13				

Date. 1904.	Helioc. Conj. G.M.T. h m	Geoc. Coord. x	Geoc. Coord. y	Semi-diam. b	Semi-duration. h m
Nov. 23	17 6				
25	2 0				
26	10 53				
27	19 47				
29	4 40	+2·8	+8·7	7·6	0 11
30	13 34				
Dec. 1	22 27				
3	7 21				
4	16 14				
6	1 8				
7	10 1				
8	18 55				
10	3 48	+2·5	+8·4	7·5	0 16
11	12 42				
12	21 35				
14	6 29				
15	15 22				
17	0 16				
18	9 9				
19	18 3	+2·2	+8·1	7·4	0 19
21	2 56				
22	11 50				
23	20 43				
25	5 37				
26	14 30				
27	23 24				
29	8 17	+1·9	+7·8	7·3	0 22
30	17 10				

As can be seen the distance of the satellite from the limb at the heliocentric conjunction on November 10 is nearly 2″, on December 19 still nearly 1″, distances in which with powerful instruments and in the most favourable conditions it will be possible to recognise *Enceladus*.

In the next year, 1905, attention may be drawn to the two eclipses of *Japetus*, the first on May 15, when *Japetus* will pass also through the shadow of the ring-system; the second, August 3, on which *Japetus* is only eclipsed by the planet. In both instances the satellite will be seen from the Earth at considerable distance from the disc of the planet and the rings. The following predictions are based on the elements of *Japetus*

deduced formerly by myself and, as to the dimensions in the mean distance, on the suppositions :

Semi-axis of the outer ring	19·79
Semi-axis of Cassini's division	17·24
Semi-axis of the inner ring	12·89
Major semi-axis of the planet	8·735
Minor „ „ „	7·825

The uncertainty of these values may produce changes of ten minutes and more in the predicted times. The computed geocentric coordinates x, y are referred to the axes of the ring.

1. *Eclipse of Japetus* 1905 *May* 15.

	G.M.T.	Geoc. Coord. x	y
	h m	"	"
Ingress into the shadow of the outer ring ...	3 34	−55·2	−25·7
Helioc. transit through Cassini's division ...	4 49	−53·1	−25·3
Ingress into the shadow of the planet	5 57	−51·3	−25·0
Egress out of the shadow of the planet	15 55	−35·0	−22·5
Ingress into the shadow of the inner ring ...	18 11	−31·3	−21·9
Helioc. transit through Cassini's division ...	20 23	−27·7	−21·4
Egress out of the shadow of the outer ring ...	21 39	−25·6	−21·0

In the first part of the phenomenon the heliocentric passage of *Japetus* through the interval between the planet and the interior ring remains invisible, as the satellite enters the shadow of the planet before coming out of the shadow of the interior ring. In the second part of the phenomenon, however, a nearly central passage through the interval and the crape-ring takes place, like the transit, predicted by Marth on 1889 November 1–2, which formed one of the most interesting observations of Barnard (*Monthly Notices*, vol. l.). Particular attention might be given to the appearance of the satellite during the transit through Cassini's division. Confusion with the other satellites is out of question, for all the other satellites are much nearer the line of the ring. As the planet on May 15 has 12° southern declination, and passes the meridian at $6\frac{3}{4}$ o'clock in the morning, this eclipse will be observed more favourably in southern observatories, while in northern observatories the low position of the planet and early twilight will render the observation difficult.

2. *Eclipse of Japetus* 1905 *August* 3.

	G.M.T.	Geoc. Coord. x	y
	h m	"	"
Ingress into the shadow of the planet (disapp.) ...	5 18	−19·6	−15·8
Egress out of the „ „ „ (reapp.) ...	8 46	−13·1	−14·8

The beginning of this eclipse can only be observed in countries east of Greenwich. For orientation it may be remarked that *Enceladus*, *Tethys*, *Dione*, and *Rhea* will be on the eastern side of the planet near the axis of the ring, and *Titan* not far from the western elongation.

Concerning the other satellites only *Tethys* will be eclipsed in the year 1905, besides *Mimas* and *Enceladus*. The reappearances of *Tethys* after the opposition, taking place at a greater distance from the planet's limb, may be well observed. The opposition of 1906 is still more favourable for these observations, as the eclipses of all the interior satellites, *Tethys*, *Dione*, and *Rhea*, still occur at sufficient distances from the ring. In the year 1907 the interior satellites move very near the axis of the ring ; in the same year the cycle of eclipses of *Titan* begins. In these years also the transits of the satellites and their shadows before the planet's disc, and the occultations and the conjunctions with the ends of the ansæ, will be worthy of particular attention.

The following tables give the times of the eclipses for the opposition of 1905 and also, for intervals of about fifteen days, the geocentric distance s of the satellite from the limb and the geocentric position-angle p, counted from the north pole of the planet (to the west for disappearance, to the east for reappearance). In computing the tables the latest elements of *Mimas* and *Tethys* (*Astron. Nachr.* vol. clxii.) are used, and the semi-axes $a_0 = 8''{\cdot}735$, $b_0 = 7''{\cdot}825$. The possible error in the predicted times should not exceed a few minutes. In the approximate indications of the eclipses published in the *Berliner Jahrbuch* for 1905 the improved elements could not be considered. *Before* the opposition only the disappearances, *after* the opposition only the reappearances are visible from the Earth.

Eclipses of Mimas, 1905.

Disappearance.

Date. 1905.	G.M.T.	s.	p. West.	Date. 1905.	G.M.T.	s.	p. West.
	h m	"	°		h m	"	°
May 25	4 24	1·0	64	June 4	13 12		
26	3 1			5	11 49		
27	1 38			6	10 26		
28	0 15			7	9 3		
28	22 53			8	7 41		
29	21 30			9	6 18	1·0	63
30	20 7			10	4 55		
31	18 44			11	3 32		
June 1	17 21			12	2 9		
2	15 58			13	0 46		
3	14 35			13	23 23		

Date. 1905.	G.M.T. h m	*s.* ′	*p.* West. °
June 14	22 0		
15	20 37		
16	19 14		
17	17 51		
18	16 28		
19	15 5		
20	13 43		
21	12 20		
22	10 57		
23	9 34		
24	8 11	0·9	62
25	6 48		
26	5 25		
27	4 2		
28	2 40		
29	1 17		
29	23 54		
30	22 31		
July 1	21 8		
2	19 45		
3	18 22		
4	16 59		
5	15 36		
6	14 13		
7	12 51		
8	11 28		
9	10 5		
10	8 42	0·8	60
11	7 19		
12	5 56		
13	4 33		
14	3 11		
15	1 48		
16	0 25		
16	23 2		
17	21 39		
18	20 16		
19	18 53		

Date. 1905.	G.M.T. h m	*s.* ″	*p.* West. °
July 20	17 30		
21	16 8		
22	14 45		
23	13 22		
24	11 59		
25	10 36	0·6	58
26	9 13		
27	7 50		
28	6 28		
29	5 5		
30	3 42		
31	2 19		
Aug. 1	0 56		
1	23 33		
2	22 10		
3	20 48		
4	19 25		
5	18 2		
6	16 39		
7	15 16		
8	13 53	0·4	56
9	12 31		
10	11 8		
11	9 45		
12	8 22		
13	6 59		
14	5 36		
15	4 13		
16	2 51		
17	1 28		
18	0 5		
18	22 42		
19	21 19		
20	19 56		
21	18 34		
22	17 11		
23	15 48	0·1	53

Eclipses of Mimas, 1905.

Reappearance.

Date. 1905.	G.M.T.	*s.*	*p.* East.	Date. 1905.	G.M.T.	*s.*	*p.* East.
	h m	″	°		h m	″	°
Aug. 23	17 39	0·0	57	Sept. 26	16 6		
24	16 16			27	14 44		
25	14 54			28	13 21		
26	13 31			29	11 59		
27	12 8			30	10 36		
28	10 46			Oct. 1	9 14		
29	9 23			2	7 51		
30	8 0			3	6 28		
31	6 38			4	5 6		
Sept. 1	5 16			5	3 43		
2	3 53			6	2 21		
3	2 30			7	0 58		
4	1 8			7	23 36		
4	23 45			8	22 13	1·9	64
5	22 23			9	20 51		
6	21 0			10	19 28		
7	19 38	0·8	60	11	18 5		
8	18 15			12	16 43		
9	16 53			13	15 20		
10	15 30			14	13 58		
11	14 7			15	12 35		
12	12 45			16	11 13		
13	11 22			17	9 50		
14	10 0			18	8 27		
15	8 37			19	7 5		
16	7 15			20	5 42		
17	5 52			21	4 20		
18	4 29			22	2 57		
19	3 7			23	1 35		
20	1 44			24	0 12	2·3	66
21	0 22			24	22 49		
21	22 59			25	21 27		
22	21 37	1·4	62	26	20 4		
23	20 14			27	18 42		
24	18 52			28	17 19		
25	17 29			29	15 56		

Date. 1905.	G.M.T.	*s.*	*p.* East.
	h m	"	°
Oct. 30	14 34		
31	13 11		
Nov. 1	11 49		
2	10 26		
3	9 3		
4	7 41		
5	6 18		
6	4 56		
7	3 33	2·5	67
8	2 10		
9	0 48		
9	23 25		
10	22 2		

Date. 1905.	G.M.T.	*s.*	*p.* East.
	h m	"	°
Nov. 11	20 40		
12	19 17		
13	17 55		
14	16 32		
15	15 9		
16	13 47		
17	12 24		
18	11 2		
19	9 39		
20	8 17		
21	6 54		
22	5 31	2·4	68

Eclipses of Enceladus, 1905.

Disappearance.

Date. 1905.	G.M.T.	*s.*	*p.* West.
	h m	"	°
May 24	22 33	0·8	58
26	7 26		
27	16 19		
29	1 12		
30	10 5		
31	18 58		
June 2	3 51		
3	12 44		
4	21 37		
6	6 30		
7	15 23		
9	0 16	0·9	58
10	9 9		
11	18 2		
13	2 55		
14	11 48		
15	20 41		
17	5 34		
18	14 27		
19	23 20		
21	8 13		

Date. 1905.	G.M.T.	*s.*	*p.* West.
	h m	"	°
June 22	17 6	0·9	58
24	1 59		
25	10 52		
26	19 45		
28	4 38		
29	13 31		
30	22 24		
July 2	7 17		
3	16 10		
5	1 3		
6	9 56		
7	18 49		
9	3 42	0·7	56
10	12 35		
11	21 28		
13	6 21		
14	15 14		
16	0 7		
17	9 0		
18	17 53		
20	2 46		

Date. 1905.	G.M.T. h m	*s.* "	*p.* West. °
July 21	11 39		
22	20 32	0·5	53
24	5 25		
25	14 18		
26	23 11		
28	8 4		
29	16 57		
31	1 51		
Aug. 1	10 44		
2	19 37		
4	4 30		
5	13 23		
6	22 16		
Aug. 8	7 9	0·3	49
9	16 2		
11	0 55		
12	9 49		
13	18 42		
15	3 35		
16	12 28		
17	21 21		
19	6 14		
20	15 7		
22	0 1		
23	8 54	0·1	44

Reappearance.

Date. 1905.	G.M.T. h m	*s.* "	*p.* East. °
Aug. 23	10 40	0·1	44
24	19 34		
26	4 27		
27	13 21		
28	22 14		
30	7 8		
31	16 1		
Sept. 2	0 55		
3	9 48		
4	18 42		
6	3 35		
7	12 29	1·0	47
8	21 22		
10	6 16		
11	15 9		
13	0 2		
14	8 56		
15	17 49		
17	2 43		
18	11 36		
19	20 30		
21	5 23		
Sept. 22	14 17	1·8	50
23	23 11		
25	8 4		
26	16 58		
28	1 52		
29	10 45		
30	19 39		
Oct. 2	4 32		
3	13 26		
4	22 19		
6	7 13		
7	16 6		
9	1 0	2·5	52
10	9 53		
11	18 47		
13	3 41		
14	12 34		
15	21 28		
17	6 21		
18	15 15		
20	0 8		
21	9 2		

Date. 1905.	G.M.T. h m	*s.* ″	*p.* East. °	Date. 1905.	G.M.T. h m	*s.* ″	*p.* East. °
Oct. 22	17 56			Nov. 9	13 32	3·2	55
24	2 49	3·0	54	10	22 26		
25	11 43			12	7 20		
26	20 36			13	16 13		
28	5 30			15	1 7		
29	14 24			16	10 1		
30	23 17			17	18 54		
Nov. 1	8 11			19	3 48		
2	17 5			20	12 41		
4	1 58			21	21 35		
5	10 52			23	6 29		
6	19 45			24	15 23	3·2	56
8	4 39						

Eclipses of Tethys, 1905.

Disappearance.

Date. 1905.	G.M.T. h m	*s.* ″	*p.* West. °	Date. 1905.	G.M.T. h m	*s.* ″	*p.* West. °
May 24	18 36	0·1	48	July 3	9 56		
26	15 54			5	7 14		
28	13 12			7	4 32		
30	10 30			9	1 51	0·3	47
June 1	7 48			10	23 9		
3	5 6			12	20 27		
5	2 24			14	17 46		
6	23 42			16	15 4		
8	21 0	0·2	50	18	12 22		
10	18 19			20	9 41		
12	15 37			22	6 59		
14	12 55			24	4 17	0·3	43
16	10 13			26	1 36		
18	7 31			27	22 54		
20	4 49			29	20 12		
22	2 7			31	17 31		
23	23 25	0·3	49	Aug. 2	14 49		
25	20 43			4	12 8		
27	18 1			6	9 26		
29	15 20			8	6 45		
July 1	12 38			10	4 3	0·2	37

Date. 1905.	G.M.T. h m	*s.* "	*p.* West. °	Date. 1905.	G.M.T. h m	*s.* "	*p.* West. °
Aug. 12	1 22			Aug. 19	14 36		
13	22 40			21	11 54		
15	19 59			23	9 13	0·1	31
17	17 17						

Reappearance.

Date. 1905.	G.M.T. h m	*s.* "	*p.* East. °	Date. 1905.	G.M.T. h m	*s.* "	*p.* East. °
Aug. 23	10 35	0·1	28	Oct. 11	12 55	2·9	42
25	7 54			13	10 14		
27	5 13			15	7 33		
29	2 32			17	4 53		
30	23 52			19	2 12		
Sept. 1	21 11			20	23 31		
3	18 30			22	20 51		
5	15 49			24	18 10	3·4	45
7	13 8	1·2	34	26	15 29		
9	10 27			28	12 49		
11	7 47			30	10 8		
13	5 6			Nov. 1	7 27		
15	2 25			3	4 47		
16	23 44			5	2 6		
18	21 4			6	23 25		
20	18 23			8	20 45	3·7	46
22	15 42	2·1	39	10	18 4		
24	13 1			12	15 23		
26	10 21			14	12 43		
28	7 40			16	10 2		
30	4 59			18	7 21		
Oct. 2	2 18			20	4 41		
3	23 38			22	2 0	3·6	47
5	20 57			23	23 19		
7	18 16			25	20 39		
9	15 36	2 9	42				

Königsberg: 1904 *August* 20.

On the Determination of Longitude on the Planet Jupiter.
By G. W. Hough.

I have read with some astonishment the paper by Mr. A. S. Williams in the *Monthly Notices* for March 1904 on the determination of longitude on the planet *Jupiter*. It is difficult to believe that he was in earnest in his presentation of the subject. As an illustration of the kind of logic employed, in paragraph 15 he asserts that in a micrometer measure of the central meridian there are four sources of error, in the observation of a transit only one source of error; hence the latter is the more accurate method. In other words, one can guess the centre of the disc better than one can measure it.

The table of so-called data consists almost entirely of the comparison of five or six observations *inter se*, selecting such as show a small mean residual. About one-third of the data cited has a mean residual of $+1^m{\cdot}0$ or less, a purely imaginary value. One minute of rotation time means $0''{\cdot}17$ of arc. The table of data is open to just criticism, but I shall simply call attention to a few grave errors.

Schmidt, Red Spot 1879–87, carried a mean error $\pm 3^m{\cdot}0$, corrected observations $\pm 1^m{\cdot}9$, *not* $\pm 1^m{\cdot}5$. Barnard, Red Spot 1880–2, carried a mean error $\pm 4^m$, *not* $\pm 0^m{\cdot}7$. Barnard, Red Spot 1891, the residual $\pm 0^m{\cdot}8$ was derived from a comparison with Marth's Ephemeris, which did not represent the motion; the true mean residual is $\pm 1^m{\cdot}8$. Williams, Red Spot 1899, carries a mean residual $\pm 2^m{\cdot}3$, *not* $\pm 3^m{\cdot}1$. Williams, Red Spot 1900, carries a mean residual $\pm 2^m{\cdot}8$, *not* $\pm 0^m{\cdot}8$. Jedrzejewicz, Red Spot 1880–1; these observations were made with the help of a micrometer, and according to the observer's own statement should carry a mean residual $\pm 2^m{\cdot}2$. The residual $\pm 0^m{\cdot}5$ is fictitious. Spots giving the short rotation period are not used at all.

From such a "discussion" he gets the following:

Mean error: Micrometer, $\pm 2^m{\cdot}0$.
„ Eye estimates, $\pm 1^m{\cdot}7$.

Hence the following logical conclusions:

1. A single eye estimate is decidedly superior in point of accuracy to micrometer measures.

2. One can bisect the disc of the planet by a single estimation with an average error of $0''{\cdot}27$ of arc, and under favourable conditions to $0''{\cdot}10$ arc. It is unnecessary to make any extended comments on such data and the inferences that may be drawn from them, but rather to add something to our knowledge of the magnitude of error in micrometer and eye-estimate work. Hitherto we have had speculation and conjecture rather than investigation regarding the limit of error in eye estimates.

Schmidt, from a discussion of all his observations on the Red Spot, 1879 to 1881, found a variable error amounting in the maximum to 8 minutes, which he thought was dependent on the hour angle of the planet. He also compared the observations made by twenty other observers, and found a range of 9 minutes in the mean personal equation. These facts were apparently established, but the causes were somewhat obscure. Schmidt thought the variable error might be due to the inclination of the belts as seen by the observer; but from his remarks on the uncertainty of the date it appears that he was not certain that this was the true explanation. It has occurred to me that it might be due to an optical illusion with which every one is familiar. If we look at the figure 8 inverted the two parts are no longer symmetrical. Now, if such variable error really exists, any discussion which aims to determine the magnitude of error is absolutely worthless if this phase of the subject is ignored.

Mr. Williams, without investigation, asserts that a variable error as indicated by Schmidt is not found in the work of other observers, "most of whom, it is believed, take the precaution of keeping the eyes parallel to the belts when observing the transits." It would appear from the above statement that Mr. Williams has never examined his own observations.

Lohse, *Potsdam Pub.* No. 9, found from his own observations mean errors $\pm 2^m{\cdot}0$ to $\pm 6^m{\cdot}0$. Hall, observations of *Saturn*, found a mean error $\pm 3^m{\cdot}0$. All these results are from the comparison of observations *inter se*, and do not necessarily represent the true error. Barnard, without any investigation, *thought* some of his observations would have a mean error $\pm 0^m{\cdot}7$. The mean error was about $\pm 4^m$. Some years ago I showed that the small residual $\pm 0^m{\cdot}7$ imagined by Barnard was a mistake, but Mr. Williams has not hesitated to incorporate it in his list of data.

Schmidt, *Ast. Nach.* 2410, gives the following for the Red Spot, 1879–81 :

	Reduced without Weight.	Empirical Corrections applied.	
	m	m	
Mean error ...	± 3·00	± 1·90	97 obs.
Probable error ...	± 2·02	± 1·28	

Mr. Williams, by a strange oversight, has assigned to these observations a mean error $\pm 1^m{\cdot}5$. Then with this fictitious value annexed he brings them forward in proof of the accuracy of eye estimates. If Schmidt's corrections were valid, which is extremely doubtful, as will be seen later, the corrected observations can no longer be regarded as eye estimates and have no place in his discussion.

It seems to me that Mr. Williams is on the horns of a dilemma with regard to Schmidt. If he admits the validity of a variable error, it requires no argument to show the untrustworthy nature of eye estimates. If, on the contrary, he denies

the existence of such error, he must accept a mean residual error $\pm 3^m.0$.

If a variable error of the magnitude assumed by Schmidt really exists in eye-estimate observations, it will seriously impair the value of the rotation period deduced. I have spent considerable time to ascertain :

1st. The magnitude of such variable error, if any.

2nd. Whether it is the same for all observers.

3rd. Whether it depends on the hour angle of the planet.

In order to accomplish this I have compared a few sets of observations by well-known observers, covering a considerable time interval, with my micrometer work for the same period.

Before making such comparison we should ascertain the amount of accidental and personal equation error in micrometer work. I have shown elsewhere that one set of measures under fair atmospheric conditions will give the time of passage over the central meridian within one minute. When the observations cover a considerable interval of time, including good and bad seeing, and are compared with an ephemeris, the mean residual (O—E) is about $\pm 1^m.5$, as may be ascertained by an examination of the work published in the *Monthly Notices* and *Ast. Nach.* The personal equation is assumed to be practically zero, for the following reasons :

1st. Measures of a spot on the same night on both sides of the central meridian indicate no constant difference.

2nd. Observations of the Red Spot during oppositions when it was nearly stationary show no irregularity in the residuals when compared with Marth's ephemeris. During the opposition a spot is measured about an equal number of times on either side of the central meridian, and hence there can be no cumulative error.

That we may clearly see the nature of the errors incident to eye estimates I have given in detail the observations made by Denning and Williams in 1887, together with my micrometer work covering the same opposition. My observations are given in standard mean time 6 hours slow of Greenwich. The others may be found in the volume *Zenographical Fragments*, by A. Stanley Williams, p. 96. The observations were compared directly with Marth's Ephemeris. I have chosen this set for the following reasons :

1st. They are the work of recognised observers.

2nd. They cover the whole opposition.

3rd. The ephemeris is by Marth, and represents the rotation period very closely. This is now known to be true by comparing it with the rotation periods of the preceding and following oppositions. I am particular in giving this detail, since the comparison of my observations shows clearly that there is no variable personal equation in micrometer measures. On 1887 July 19 and 22 the longitude measures were made respectively 63^m east and 41^m west of the central meridian of the disc.

The longitude differences are almost identical, a good proof that the personal equation was zero.

These observations are a fair average of the kind of work done by all observers when the time interval is considerable. The table is worthy of serious study by any one who imagines the eye-estimate method is capable of yielding results of precision, such as are demanded in other lines of astronomical work.

Hough.				Denning-Williams.				
1887.	T. h m	Long. m	O—E. m	1886.	Long. m	O—E. m	Actual Error. m
Jan. 28	18 02·3	— 9·3	—1·3	Nov. 23	— 2·5 D.	+ 9·0	+ 5·5
Mar. 8	15 14·9	— 6·3	+1·7	Dec. 17	— 4·9 D.	+ 6·6	+ 3·1
Apr. 7	9 54·0	— 9·8	—1·8	20	—11·0 W.	+ 0·5	— 3·0
24	8 56·4	— 6·3	+1·7	1887.			
29	8 00·7	— 9·2	—1·2	Jan. 1	— 6·0 „	+ 5·5	+ 2·0
May 13	9 31·0	— 9·9	—1·9	Feb. 26	— 4·8 „	+ 6·7	+ 3·2
18	8 46·6	— 1·8	+6·2	Mar. 20	— 3·9 „	+ 7·6	+ 4·1
28	6 57·1	— 7·1	+0·9	27	— 6·9 „	+ 4·6	+ 1·1
June 8	11 00·4	— 7·2	+0·8	29	—15·8 „	— 4·3	— 7·8
11	8 29·1	— 8·3	—0·3	Apr. 3	— 9·9 „	+ 1·6	— 1·9
13	10 09·1	— 6·9	+1·1	10	—21·8 „	—10·3	—13·8
16	7 38·7	— 7·3	+0·7	17	—12·7 „	— 1·2	— 4·7
23	8 23·6	— 9·7	—1·7	20	—13·8 „	— 2·3	— 5·8
25	10 02·9	— 8·2	—0·2	24	—15·2 „	— 3·7	— 7·2
28	7 29·9	—12·2	—4·2	27	—14·9 „	— 3·4	— 6·9
July 7	10 00·7	— 7·9	+0·1	29	—17·9 „	— 6·4	— 9·9
12	9 11·3	— 6·5	+1·5	May 2	—15·6 „	— 4·1	— 7·6
19	9 55·5	—10·5	—2·5	7	—15·5 D.	— 4·0	— 7·5
22	7 25·7	—10·9	—2·9	9	—15·5 W.D.	— 4·0	— 7·5
29	8 13·9	— 6·0	+2·0	10	—13·8 D.	— 2·3	— 5·8
Mean Long.		— 8·0	±1·7	14	—15·1 W.	— 3·6	— 7·1
				26	—14·8 D.	— 3·3	— 6·8
				June 10	—11·3 D.	+ 0·2	— 3·3
				19	—21·0 W.	— 9·5	—13·0
				22	— 6·1 D.	+ 5·4	+ 1·9
				July 16	— 5·8 D.	+ 5·7	+ 2·2
				Aug. 6	— 4·2 D.	+ 7·3	+ 3·8
				Mean Long.	—11·5	± 4·7	± 5·6

The column "Long." is the longitude in time from Marth's Meridian II. The column "Actual Error" is the difference between the observed longitude and the true longitude resulting from the micrometer measures. The residuals O—E, for both micrometer

and eye estimates, represent the accidental error of observation without regard to any personal equation. For this set the mean residual O−E was, for the micrometer $\pm 1^m\cdot 7$, for eye estimates $\pm 4^m\cdot 7$. The actual mean error for eye estimates was $\pm 5^m\cdot 6$. The combined personal equation for Denning and Williams was $-3^m\cdot 5$. When the observations of the two observers are treated separately we find for the mean personal equations :

	m
Denning	−1·4
Williams	−4·4

An inspection of the column of longitudes shows very clearly a variable error which amounted to about ten minutes, but it did not vary in the same way for both observers. Denning obtained the same longitude differences at the beginning and end of the series, but changed his longitude about ten minutes in the middle. Williams on the other hand began with nearly the same longitude as Denning, but suddenly about April 1 changed about ten minutes and continued pretty steadily on the new longitude to the end of the series. These observations do not show any direct connection between the hour angle of the planet and the variable error, as had been assumed by Schmidt.

Mr. Williams remarks : "The mean rotation period, November 1886 to May 1887, was $9^h\ 55^m\ 38^s\cdot 8$; May to August, $9^h\ 55^m\ 44^s\cdot 0$. Making use of observations near the beginning and end of the series, the mean period is $9^h\ 55^m\ 40^s\cdot 51$." He also says the irregularities in the motion may be due to the different positions of the planet before and after opposition.

Messrs. Denning and Williams are experienced observers and do as good work as can be done by the method used. Yet it is readily seen how erroneous may be the conclusions drawn from such observations. Here we have apparently a well-established fluctuation in the rotation period of 5·2 seconds which did not exist. The residuals for the micrometer observations show that the rotation period was sensibly stationary, and was practically the same as that used for the ephemeris, viz. $9^h\ 55^m\ 40^s\cdot 63$.

Now having clearly shown that the micrometer is free from cumulative error due to a variable personal equation, we may examine a few sets of observations by other well-known observers. The following table indicates some of the results. To give the observations in detail would consume too much space. It may be said, however, that persistence in error in one direction, in some cases, is even more apparent than in the example already given.

Object.	Time Interval. Days.	No. Obs.	O−E.	Mean Personal Equation.	Observer.
			m	m	
Red Spot 1891 ...	242	23	±1·7	...	Ho.
„ ...	122	11	±1·8	−5·8	Barnard
Long Red 1891 ...	117	12	±2·0	...	Ho.

Object.	Time Interval. Days.	No. Obs.	O−E.	Mean Personal Equation.	Observer.
			m	m	
Long Red 1891	... 85	13	±1·7	−2·5	Barnard
Small Black 1891	(*a*) 119	10	±1·5	...	Ho.
„	(*a*) 92	7	±5·3	−5·8	Barnard
„	(*b*) 85	13	±4·2	0	Barnard
Red Spot 1899	... 225	27	±1·6	...	Ho.
„	... 95	9	±2·3	−7·7	Williams
Red Spot 1900	... 199	17	±1·3	...	Ho.
„	... 113	4	±2·8	−7·3	Williams
Black Spot 1898	... 191	18	±2·2	...	Ho.
„	... 144	24	±4·1	−2·4	Gledhill
Red Spot 1887	... 182	20	±1·7	...	Ho.
„	... 252	10	±4·7	−1·4	Denning
„	... 181	17	±4·9	−4·4	Williams

The variable personal equation was :

Barnard ...	Red Spot	Beginning -2^m	End -7^m
„ ...	Long Red	Not well indicated	
„ ...	Small Black (*a*)	Beginning -15^m	„ 0
„ ...	„ (*b*)	„ -4^m	„ $+3^m$
Williams...	Red Spot 1899	Not well indicated	
„ ...	„ 1900	Beginning −3	„ +3
Gledhill ...	Black Spot 1898	„ −4	„ +6
Denning ...	Red Spot 1887	Beginning and end +4	Middle −5
Williams...	„ „	Beginning +3	Middle and end −7

The numbers indicating variable personal equation are the average of a number of contiguous observations, and are necessarily approximate.

The spots *a* and *b* observed by Barnard in 1891 present a curious phase in eye-estimate observations. Barnard observed both spots on the same night at the beginning and end of the series. The other observations alternate on different nights. The two spots were in the same latitude and in close proximity, the difference of longitude by the micrometer being $24^m{\cdot}8 \pm 0^m{\cdot}6$. Barnard's observations give $30^m{\cdot}8 \pm 0^m{\cdot}9$, or a constant error of six minutes in the distance between them. The mean personal equation, as already given, indicates the same constant error. In other words, his central meridian differed $5^m{\cdot}8$ for the two spots.

The following inferences may be drawn from the above data :

1st. In all cases the "mean" personal equation was negative,

which means that observations on the average were made too soon, or before the spot reached the central meridian.

2nd. There is apparently no real personal equation as the term is understood in precision observations. In eye-estimate observations the term personal equation, which I use for convenience, seems to be made up of accidental error taken in connection with the peculiar method employed in making the observations. It is easily understood why an observer may record five minutes too soon on one night and five minutes too late on the next night, but why we should persist in recording ten minutes too soon or too late over a long interval I am unable to explain.

3rd. The mean residual O—E from a comparison with the ephemeris is more than twice as great as for the micrometer, some observations of the Red Spot excepted.

4th. These residuals represent the average accidental error of observation, not including the mean personal equation.

5th. The real error at any point is the algebraic sum of the residual and the mean personal equation.

6th. The "mean" personal equation is not the same for the different spots observed.

7th. The personal equation is not constant, but may change so much during the opposition as to greatly impair the value of the rotation period.

8th. The number for variable personal equation taken in connection with the mean residual indicates that an observer may be persistently in error ten to fifteen minutes in determining the time of passage of a spot over the central meridian of the disc. This conclusion is confirmed by a great number of observations published during the past twenty-five years (vide *Monthly Notices*, "Comparison of observations by Marth and others").

The observations mentioned above do not show any law connecting the variable error with the hour angle of the planet. I think it highly probable that Schmidt's explanation was erroneous.

The accidental error in eye estimates is not nearly so serious a defect as the variable error. If the observer at the end of one hundred days observes fifteen minutes earlier or later than at the beginning, the rotation period deduced will be considerably in error.

The variable persistent error is undoubtedly responsible for the erroneous deductions regarding the motion of the Red Spot and other spots which have been published frequently at different times in past years. A favourite way to account for discordant observations is to assume irregular motion in the spot. Although the motion of no spot on *Jupiter* can be regarded as constant for a long interval yet there is never any abrupt change in its drift, as indicated by my observations for the past twenty-five years. When the time interval is less than one hundred days the observations usually can be fairly satisfied

by assuming a uniform rotation period. Occasionally, however, it is necessary to use a variable rotation period to bring the residuals within the probable errors of observation. Examples of this kind may be found in *Monthly Notices*, lii. 412, and *Ast. Nach.* 3354.

The personal equation problem is one of so much importance that I have made a few additional comparisons, to ascertain its amount in different years. For convenience of reference all the data are arranged in the following table :

		Mean Pers. Eq.	Variable.
	Denning.	m	m
Red Spot	1880	−4·6	6
,, ...	1883	−7·7	6
,, ...	1885	−3·2	
,, ...	1887	−1·4	6
,, ...	1901	−2·5	
White Spot	1881	0	3
	Williams.	m	m
Red Spot	1887	−4·4	10
,, ...	1899	−7·7	
,, ...	1900	−7·3	5
,, ...	1902	−2·9	6
White Spot	1881	+0·8	7
Spot (*a*)	1898	−5·9	3
	Schmidt.	m	m
Red Spot	1880 Sept.	−8·3	±0·7
,, ...	Nov.	−0·6	±1·5
,, ...	1881 Jan.	−4·0	±1·0

Denning, 1880.—The personal equation was derived from five consecutive observations at two dates, October 11 and December 20, giving respectively $-7^m\cdot7$ and $-1^m\cdot5$ with a probable mean error less than $\pm1^m$.

Schmidt's observations were treated in the same manner for the dates given. It is readily seen that there is no constancy in the mean personal equation from year to year.

During the opposition the variation is usually in one direction only. In view of the difficulty in making an observation it is possible that these abnormal results are simply due to accidental error.

As an illustration of the uncertainty involved in eye estimates

I refer to one of Barnard's observations of a white spot on *Saturn* (*Astronomical Journal*, No. 547).

	h	m	
1903 August 2	13	46	Very nearly in transit.
		49	Perhaps not yet in transit.
		52	In transit.
		56	„ „
		58	Perhaps in transit.
	14	00	Perhaps past; a little uncertain.
		02	„ „ „ „
		08	Past, but not decidedly so.
		14	Decidedly past transit.

The time adopted was $13^h\ 57^m$, which is five minutes later than the first recorded transit. From the data given I should adopt 13·54 as the most probable value.

In this example, for an interval of nineteen minutes, a space equal to 1″·6 of arc, the observer was uncertain whether the spot was on the central meridian or not. And for an interval of six minutes, or a space of 0″·5 arc, he was sure it was on the central meridian. On the planet *Jupiter*, on account of the greater size of the disc, the uncertainty in the time of transit would be about one-half as great as for *Saturn*. Mr. Williams and other observers do not seem to understand the nature of the problem involved in eye estimates or transits, viz. the space in seconds of arc that the eye can discriminate.

I can say with certainty that no spot on *Jupiter* of 0″·5 in diameter has ever been observed for rotation time, and probably none less than 1″ of arc. At mean distance 1″ of arc on *Jupiter* corresponds to 5·5 minutes of rotation time.

Adopting the space values as given for *Saturn* there would be an interval of 9 minutes during which the observer might be in doubt regarding the transit, and an interval of 2·8 minutes when he was sure the spot was in transit.

The absurdity of the claim for a mean error $\pm 1^m\cdot 0$ or 0″·2 of arc is apparent.

It is a curious anomaly, however, that the Red Spot, the most difficult object on the disc of late years, when the rotation period was nearly stationary, has apparently furnished this small residual error, while other spots, for which there was no ephemeris, but were capable of much more accurate determination, in the majority of cases yield a mean error ± 3 to ± 5 minutes.

Mean Error.

Mr. Williams in his extended remarks on error does not seem to apprehend the difference between mean or probable error and constant error. Without discussing the question I may say

that the errors derived in my report, 1882, were determined in the usual way and are correct. The residuals when observations are compared with an ephemeris are made up of mean error, constant error, and variable motion.

In *Monthly Notices*, lii. 412, for the Red Spot the mean residual for uniform motion was $\pm 1^m\cdot 7$, for variable motion $\pm 1^m\cdot 2$. In my report for 1882 the observations of the Red Spot from 1879 September 25 to 1882 March 29, a period of 916 days, are compared with an ephemeris in which the rotation period increased with the time. Mr. Williams, perhaps inadvertently, stated that Schmidt's observations from 1879 November 10 to 1881 March 20 gave a mean error of $\pm 1^m\cdot 5$, "exactly the same as mine." Schmidt's mean error was $\pm 3^m\cdot 0$.

Identification of Spots.

I am at a loss to know what Mr. Williams requires for the identification of a spot on *Jupiter*. Here are four observations which he says belong to three different spots :

Days.	O−E.	App. Lat.
	m	
0	+0·0	−0″·93
37	+3·3	...
78	+0·8	−1·74
80	+0·1	−1·61

This spot is identified both by latitude and longitude. The longitudes are represented by a mean error of $\pm 1^m\cdot 0$, and the latitudes are well within the limit of error, the first observation differing only 0″·50 from the mean. I venture to say that neither Mr. Williams nor anybody else has ever made a more certain identification.

Three observations of a spot at unequal intervals of time are sufficient to definitely fix the rotation period. The spots I observe are generally identified by both longitude and latitude, whereas in eye estimates one must rely on longitude only.

Mr. Williams remarks that about 40,000 transits have been observed, "and that these constitute the foundation of much of our knowledge of the rotation of *Jupiter* and the various surface currents known to exist," &c. He has also remarked on another occasion that eye estimates could accomplish all that can be done with the micrometer. I have grave doubts regarding both statements. I have repeatedly urged that the element of latitude is of equal value with that of longitude in arriving at a knowledge of the conditions of the surface of the planet.

The foregoing discussion proves conclusively the existence of a variable error, even beyond the limits assigned by Schmidt. All the observers, in the examples cited, without exception, either gradually or suddenly changed the zero of reference in

some cases 10 minutes or more. Such an error corresponds to about 2″ of arc on the disc of *Jupiter*. It also shows that the ordinary accidental error is fully as large as has been stated by others, viz. 3 to 5 minutes. Hence I infer that for a short time interval, viz. 30 days or less, the method is absolutely worthless in so far as securing a trustworthy rotation period is concerned.

On the contrary, when the time interval is more than 200 days the combination of the work of a number of observers may yield a fair mean rotation period, but in no case is it capable of disclosing a variable rotation period, or, in other words, representing the true motion of the spot or marking. The method of eye estimates was used before modern instruments of precision were known. It was then the only method available. I think now no astronomer who has the necessary apparatus would employ it if he fully understood the uncertainty of the results.

References.

The Red Spot, 1880	Hough	... ...	*Report Chicago A. S.* 1882
„ „	Denning	... ...	*M. N.* xli. 358.
„ „	Schmidt	... ...	*A. N.* 2410
„ 1883	Denning	... ...	*M. N.* xliv. 64
„ 1885	„	... ...	„ xlvi. 117
„ 1901	„	... ...	*Observatory*, xxiv. 313
„ 1899	Williams	... ...	*A. N.* 3596
„ 1900	„	... ...	„ 3675
„ 1902	„	... ...	„ 3875
„ 1899	Hough	... ...	*M. N.* lx. 550
„ 1891	„	... ...	„ lii. 412
„ „	Barnard	... ...	„ „ 12
Long Red, 1891	„	... ...	„ „ 10
Spots *a* and *b*, 1891	„	... ...	„ „ 13
„ „ „	Hough	... ...	„ „ 415
Long Red, 1891	„	... ...	„ „ 413
Black Spot *a*, 1898	„	... ...	„ lx. 552
„ „ „	Gledhill	... ...	„ lviii. 500
„ „ „	Williams	... ...	*Observatory*, xxi. 341
White Spot, 1881	„	... ...	*M. N.* xlii. 428
„ „	Denning	... ...	„ „ „
„ „	Hough	... ...	*Report Chicago A. S.* 1882

Observations of the Satellite of Neptune from Photographs taken at the Royal Observatory, Greenwich, between 1903 December 4 and 1904 April 18.

(*Communicated by the Astronomer Royal.*)

The following measures of position angle and distance of *Neptune's* satellite were made from photographs taken with the 26-inch refractor of the Thompson equatorial. The occulting shutter was used, as in previous years, the photographs being taken by Messrs. Davidson, Edney, or Melotte. The photographs were measured in a position micrometer in direct and reversed positions by Mr. Dyson and Mr. Edney. The tabular positions with which comparison is made were computed from the data given in the *Connaissance des Temps*, based on Dr. H. Struve's elements, the eccentricity of the orbit being neglected on account of the uncertainty in the present position of peri-astron. For fuller particulars as to the photographs and their measurement reference may be made to a previous paper in the *Monthly Notices*, vol. lxii. pp. 622–626.

NEPTUNE AND SATELLITE.

Position Angle and Distance, from Photographs taken with the 26-inch Refractor.

Date and G.M.T.					Position Angle.			Distance.			Remarks.
					Observed.	Tabular.	T−O.	Observed.	Tabular.	T−O.	
1903.	d	h	m	s	°	°	°	″	″	″	
Dec.	4	11	20	34	97·25	97·70	+0·45	16·46	16·56	+0·10	
	8	12	32	26	225·60	226·72	+1·12	13·28	13·40	+ ·12	
	9	11	25	46	145·03	146·41	+1·38	12·32	11·98	− ·34	
	9	12	10	35	142·94	143·97	+1·03	12·11	12·15	+ ·04	
	10	11	8	18	91·03	92·95	+1·92	16·76	16·80	+ ·04	
	10	11	47	50	91·53	91·86	+0·33	17·02	16·81	− ·21	
	14	10	43	25	223·17	223·66	+0·49	13·03	13·13	+ ·10	
	15	11	40	23	135·15	136·47	+1·32	12·68	12·72	+ ·04	
	17	10	26	21	40·08	40·32	+0·24	13·05	12·84	− ·21	
	30	11	14	11	297·34	298·44	+1·10	14·36	14·49	+ ·13	
	30	11	51	15	296·50	297·11	+0·61	14·54	14·62	+ ·08	
	31	11	11	28	254·55	255·18	+0·63	16·71	16·44	− ·27	Definition very poor.
	31	11	42	41	252·84	254·26	+1·42	16·28	16·37	+ ·09	Definition very poor.
1904.											
Jan.	6	10	55	54	249·35	250·28	+0·93	15·83	16·04	+ ·21	
	13	9	1	24	177·16	179·21	+2·05	11·15	11·00	− ·15	
	13	9	33	25	176·68	177·04	+0·36	11·10	10·99	− ·11	
	14	10	4	22	105·00	105·53	+0·53	16·09	15·79	− ·30	
	14	10	39	39	103·04	104·42	+1·38	15·98	15·90	− ·08	
	15	10	0	32	62·79	63·48	+0·69	15·25	15·34	+ ·09	

Date and G.M.T.				Position Angle.			Distance.			Remarks.
				Observed.	Tabular.	T−O.	Observed.	Tabular.	T−O.	
1904.	d	h	m s	°	°	°	″	″	″	
Jan.	15	10	26 13	61·61	62·61	+1·00	15·22	15·25	+·03	
	15	10	50 46	60·48	61·77	+1·29	15·21	15·16	−·05	
	16	10	26 49	348·52	347·94	−0·58	(10·50)	11·05	+(·55)	Definition poor.
	19	9	51 5	164·71	164·60	−0·11	11·02	11·11	+·09	
	19	10	40 35	159·81	161·47	+1·66	10·92	11·19	+·27	Definition poor.
	22	8	5 12	344·93	345·77	+0·84	11·25	11·07	−·18	Definition very poor. Satellite elongated.
Feb.	2	9	50 18	44·36	43·34	−1·02	13·06	13·15	+·09	
	5	8	47 49	222·16	222·16	0·00	12·95	13·04	+·09	
	5	9	13 49	220·51	220·96	+0·45	12·82	12·92	+·10	
	5	9	38 35	219·55	219·80	+0·25	12·76	12·82	+·06	
	5	9	58 30	217·28	218·85	+1·57	12·72	12·74	+·02	
	6	9	29 55	135·26	135·59	+0·33	12·15	12·52	+·37	Satellite diffused and touching halo of the planet.
	13	7	49 43	83·62	83·67	+0·05	16·64	16·70	+·06	
	13	8	17 55	82·70	83·90	+1·20	16·67	16·69	+·02	
	15	9	13 47	302·83	304·19	+1·36	13·45	13·51	+·06	
	15	9	48 6	301·56	302·76	+1·20	13·57	13·66	+·09	
	17	9	22 7	202·12	202·07	−0·05	11·37	11·52	+·15	
	17	9	49 38	199·97	200·52	+0·55	11·48	11·44	−·04	
Mar.	10	7	47 25	281·40	281·73	+0·33	15·53	15·68	+·15	
	10	8	17 37	280·48	281·12	+0·64	15·76	15·73	−·03	
	11	8	13 44	237·91	238·79	+0·88	14·40	14·59	+·19	Definition very poor.
	11	8	43 53	237·77	237·72	−0·05	14·74	14·47	−·27	Definition poor.
	11	9	14 52	236·23	236·60	+0·37	14·69	14·35	−·34	Definition poor.
	11	9	48 4	233·56	235·38	+1·82	14·14	14·21	+·07	Definition poor.
	21	8	36 48	324·13	324·42	+0·29	(10·98)	11·57	+(·59)	Satellite badly defined and in halo of the planet.
	21	9	7 8	321·21	322·86	+1·65	11·40	11·67	+·27	Definition poor.
	21	9	38 58	319·15	321·15	+2·00	(11·10)	11·78	+(·68)	
	21	10	14 2	317·92	319·29	+1·37	11·70	11·91	+·21	
Apr.	6	8	0 6	78·02	79·19	+1·17	15·63	16·11	+·48	
	6	8	33 43	77·54	78·24	+0·70	15·83	16·06	+·23	
	12	8	8 59	72·69	73·92	+1·23	15·48	15·74	+·26	
	16	8	24 55	184·53	185·52	+0·99	10·61	10·59	−·02	Definition poor.
	16	9	1 35	182·40	183·15	+0·75	10·36	10·55	+·19	
	18	8	25 5	68·36	68·15	−0·21	15·04	15·20	+·16	
	18	9	4 50	66·84	66·91	+0·07	14·80	15·08	+·28	Definition very poor.

New Variable Stars found on the Astrographic Plates at the Royal Observatory, Greenwich.

(*Communicated by the Astronomer Royal.*)

In the course of the work for the *Astrographic Catalogue* under Mr. Hollis's direction a star whose approximate position for 1900 is R.A. $8^h\ 14^m\ 5^s$, Dec. $+73°\ 25'·6$, has been found to be variable to the extent of about three magnitudes. The following table gives the measured diameter (unit $= 0''·15$) and that of neighbouring comparison stars whose magnitudes have been inferred from the formulæ

$$m = 16·1 - 0·84\sqrt{d} \text{ for exposure 40 minutes}$$
$$m = 13·7 - 0·77\sqrt{d} \quad \text{,,} \quad 6 \quad \text{,,}$$

given in vol. i. of the Greenwich Section of the *Astrographic Catalogue*, p. xxx. The magnitude of the variable on the different plates is readily obtained by comparison with these standards.

No. of Plate.	Date.	Exp.	Measured Diameters.							Deduced Mag. of Variable.
			Var.	*a.*	*β.*	*γ.*	*δ.*	*ε.*	*ζ.*	
				m 13·0	m 12·1	m 11·5	m 10·8	m 10·0	m 9·6	
		min.								m
3782	1897 Dec. 20	40	20	—*	20	30	42	54	62	12·1
4288	1898 Feb. 21	40	16	12	22	26	42	66	64	12·6
4320	1899 27	40	38	6	16	24	34	38	50	10·0
4361	1899 Mar. 11	40	16	14	22	32	42	56	64	12·8
4761	1900 Jan. 2	6	5	6	12	19	26	38	44	13·1
4793	1900 24	6	22	3	8	11	20	26	34	10·5
6004	1902 Mar. 25	40	22	10	16	20	30	40	42	11·4
6010	1902 27	40	28	12	18	24	36	46	58	11·3

The positions of the variable and reference stars are as follows :

	Zone and No. in *Astrogr. Catalogue.*	Zone and No. in B.D.	Approximate Position, 1900. R.A.	Dec.
			h m s	° ′
Variable	73, 3544		8 14 5	73 26
α	73, 3547		8 17 12	73 28
β	73, 3514		8 16 34	73 15
γ	73, 3525		8 16 18	73 15
δ	73, 3545		8 16 21	73 29
ε	73, 3509	73°, 417	8 21 8	73 7
ζ	73, 3523	73, 411	8 13 56	73 19

A star, whose approximate position for 1900·0 is R.A. $19^h\ 40^m\ 38^s$, Dec. $+80°\ 42'$, is suspected of being variable, and further photographs are being taken for comparison.

* Not shown, owing to fog on plate.

New Empirical Term in the Moon's Longitude.
By P. H. Cowell.

Tisserand, *Mécanique Céleste*, vol. iii. p. 417, after tabulating the Moon's errors from 1620 to 1888 and discussing Newcomb's empirical term of 273 years, says :

"La représentation est satisfaisante en général ; toutefois, il subsiste des indices d'une autre inégalité, à période moindre, et ayant un coefficient de 2″ à 3″."

I believe that I have succeeded in fixing the period of this term at 69 ± 3 years. Its coefficient is about 2″, and it reaches a maximum value about 1825.

At the earliest opportunity I hope to publish a full analysis.

M. Radau has kindly referred to his calculations of planetary inequalities, and he has informed me that the two terms with arguments $g - 14\mathrm{E} + 9\tau$ and $\varpi + 8\mathrm{E} - 5\mathrm{V}$, which are approximately of the right period, have insensible coefficients.

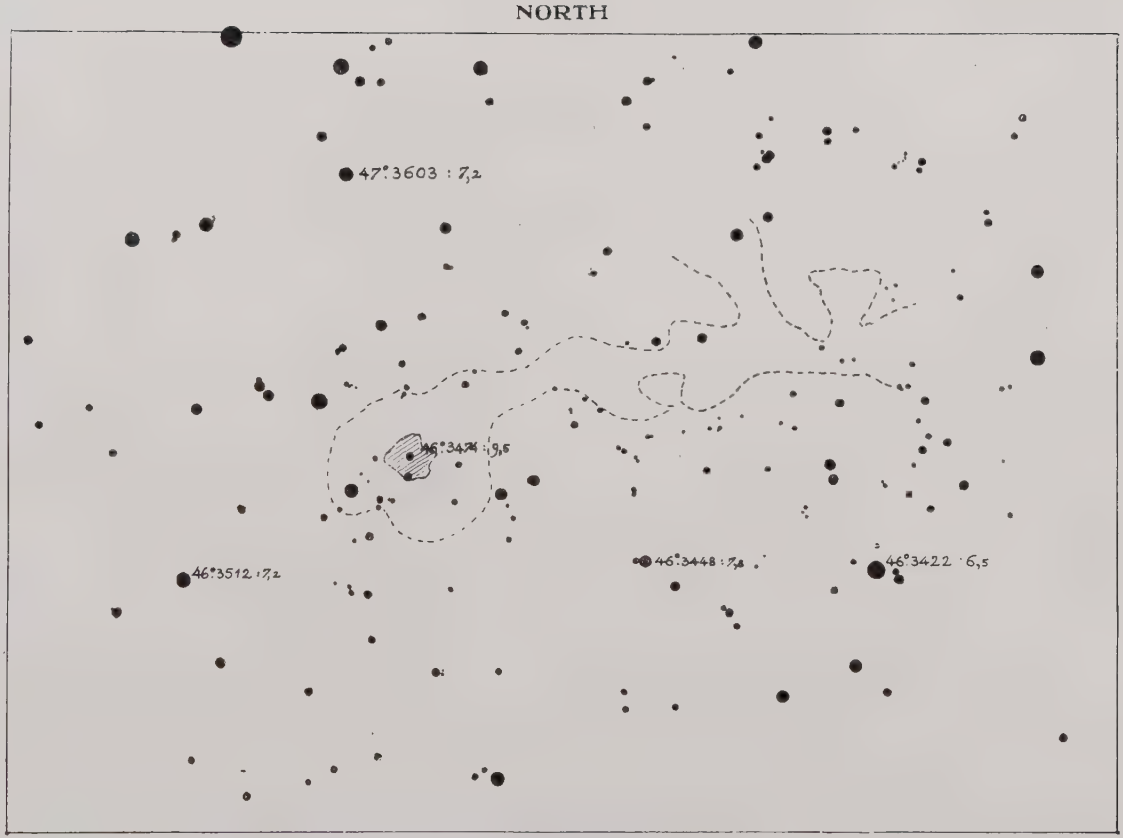
A Remarkable Nebula in Cygnus connected with Starless Regions.
By Dr. Max Wolf.

In earlier papers I have pointed out that there seems to exist a curious relation in the distribution of extended nebulæ and fainter stars. I had found that all extended nebulæ discussed at our Observatory are situated in the interior of regions containing only a very small number of faint stars. It afterwards appeared that Sir William Herschel had some idea of this remarkable fact. We have been able to show that the two great *Orion* nebulæ, as well as the North America nebulæ in *Cygnus*, are surrounded by and are situated at the edge of regions nearly void of faint stars. My assistant, Mr. Kopff, has published an exact enumeration of the stars about these objects,* from which it is proved that nearly all faint stars have disappeared from the immediate surroundings of these nebulæ, though they are about ten times more numerous both in the nebulæ themselves and far outside. The few stars remaining in the lacunæ belong to the brighter magnitudes.

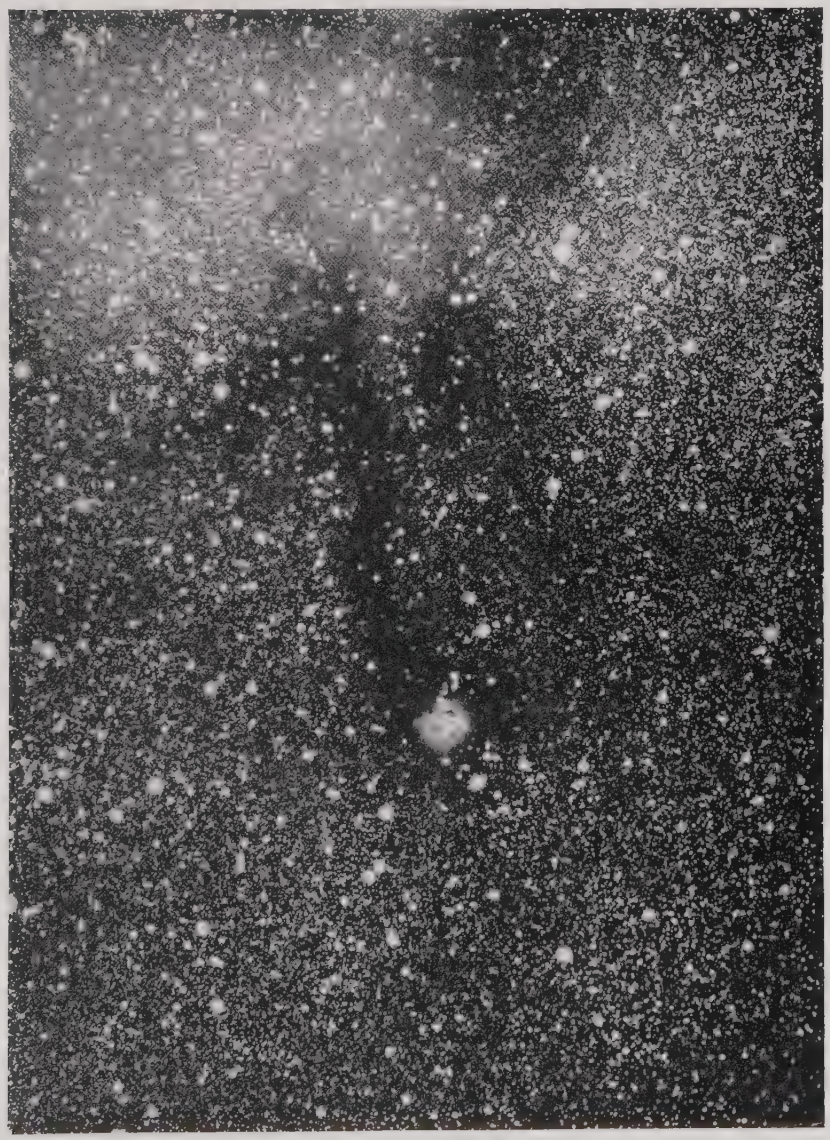
Similar relations seem to exist for all extended nebulæ. In addition to the above named the same is the case with regard to the following objects :

The great nebula Messier 8, *Sagittarii*.
" " " 20, "
" " *γ Scuti*.
" " *ρ Ophiuchi*.
" " *δ* "

* *Publ. d. Astrophys. Obs. Königstuhl*, i. 177.



KEY MAP



DETACHED NEBULA IN CYGNUS.

The great nebula north of *Antares.*
" " *ν Scorpii.*
" " *η Carinæ.*
" " *S Monocerotis.*
" " *ξ Persei.*
" " *β Cassiopeiæ.*
" " near *γ Cygni*, &c.

All these examples show the above-mentioned relation, and also the fact that, though partially or wholly surrounded by void zones, the nebulæ are generally placed at the end of a longer extended lacuna, so that we are led to the impression that we here see the result of some cosmic movement, the end of the lacuna showing the place where this unknown event began.

I had already found something similar in the Triple Cave of *Aquila*, but not typical enough for discussion. The photograph accompanying the present paper shows an extremely curious example of these relations.

This nebula is situated about 2° south-east of π^2 *Cygni*, and involves in its centre the 9·5 mag. star B.D.+46°, 3474, the coordinates of which are given by Argelander for 1855·0, viz.:

$$\text{R.A.} = 21^h\ 47^m\ 54^s{\cdot}4 \quad \text{Decl.} = +46°\ 34'{\cdot}9.$$

A second *Durchmusterung* star is enclosed by the same nebula, somewhat more south; it is the 9·3 mag. star B.D.+46°, 3475, which has the position:

$$\text{R.A.} = 21^h\ 47^m\ 55^s{\cdot}3 \quad \text{Decl.} = +46°\ 30'{\cdot}9.$$

This star is situated near the southern edge of the nebula. The object was photographed by myself for the first time on 1894 July 28 with a 6-inch camera. The last picture obtained, which is reproduced here, was taken 1904 July 10 with the 16-inch camera, with 240 minutes' exposure. The reproduction (Plate 18) is made from a part of one of the original plates on the scale of 1° = 60 mm.

The nebula is somewhat round and is about 10′ in diameter. It is of a very complicated structure, somewhat resembling the trifid nebula in *Sagittarius*. It is placed centrally in a very fine lacuna, void of faint stars, which surrounds the luminous cloud like a trench. The most striking feature with regard to this object is that the star-void halo encircling the nebula forms the end of a long channel, running eastward from the western nebulous clouds and their lacunæ to a length of more than two degrees.

The channel is somewhat similar to one of the three arms of the *Aquila* Triple Cave (reproduced in *Knowledge*, xxv. p. 203).

The nebulous clouds to the west, partly visible at the right edge of the picture, are placed near a region likewise poor in faint

stars, a large barren tract spread over many square degrees from south to north in the Milky Way.

In regarding this nebula we are led to speculation. We might suppose the nebula were detached from the great western nebulous cloud, and as if it, or the cosmic process connected with its origin, had swept the long channel through the star-crowds of the Milky Way. Or is there a dark mass following the path of the nebula, absorbing the light of the fainter stars? We are far from knowing enough to settle these questions; but one thing we learn anew from this interesting nebula, and in a very illustrative manner—*that the nebula is geometrically encircled by a ring which is void of faint stars, and that this lacuna is the end of a long starless hole.*

Königstuhl Astrophysical Observatory:
1904 *August.*

Dr. Brooks's Discovery of his Twenty-fourth Comet.

By William R. Brooks, D.Sc.

I have the honour to announce to the Society the discovery of a new comet on the evening of April 16 last, in the constellation *Hercules*. Its position at the moment of discovery, $9^h\ 50^m$ standard mean time, was R.A. $16^h\ 58^m\ 10^s$; declination north $44°\ 10'$.

Its cometary character was detected the instant the object was swept into the telescopic field, for it had all the appearance of a great comet in miniature, a head with stellar nucleus and a tail. I enclose herewith a drawing of the telescopic field at discovery (fig. 1). When first seen the comet was nearly midway between the stars D and E, and also nearly on a line drawn from the star A to B. The rate of motion was quite slow, but in about an hour it had moved into a line drawn from A to C.

The following evening was clear, and an observation at $8^h\ 15^m$ made the comet's position R.A. $16^h\ 55^m\ 5^s$, Decl. $+44°\ 48'$, giving a daily motion of about three-quarters of a degree in a north-westerly direction.

It was a conspicuous object in the 10-inch refractor with which it was discovered, the nucleus being at times quite prominent and sparkling, while the tail in good air could be readily seen to the edge of a half-degree field. The comet was always visible in the 3-inch finder. It must really be quite a large comet, for at discovery its distance from the Earth was not far from three hundred millions of miles, and it had passed perihelion several weeks before. With two exceptions its perihelion distance is greater than any other known comet, the mean of several computations by different computers being 2·707. At first an elliptical orbit was computed, with the remarkably short period

of about three years. The orbit is probably, however, a parabola, the latest elements received at this writing, as issued from the

FIG. 1.—Telescopic Discovery Field of Brooks's Comet, *a* 1904.

Lick Observatory by Messrs. Atkin and Maddrill, from observations on April 17, May 8, and May 24, being as follows :

$$T = 1904 \text{ March } 6{\cdot}9049 \text{ G.M.T.}$$

$$\left.\begin{aligned} \omega &= 53\ 27\ 13{\cdot}8 \\ \Omega &= 275\ 46\ 05{\cdot}5 \\ i &= 125\ 07\ 33{\cdot}1 \end{aligned}\right\} \text{M. Eq. } 1904.$$

$$\log. q = 0{\cdot}432475.$$

The comet's position being most favourable for observation, and being visible the entire night, a large number of observations have been secured, the latest being last night, July 11, $11^h\ 5^m$ standard M.T., when its approximate place was R.A. $12^h\ 27^m\ 30^s$, Decl. $+51°\ 14'$. The most northerly position observed here was on June 10, when it equalled $+56°\ 57'$.

Although theoretically the comet should have grown fainter subsequent to its discovery the decline was so slow as to be imperceptible for some weeks ; indeed there were times when it appeared considerably brighter than it was at discovery. I am inclined to attribute this appearance to actual fluctuations in brightness (as noted in other instances) as well as to changes in

the clearness of the sky—a very variable quality indeed, even when the sky is quite free from clouds, in this very delightful lake region of America. I select a few of many observations :

April 22. $9^h\ 50^m$.

Position R.A. $16^h\ 40^m\ 45^s$, Decl. $+47°\ 50'$.

Easily seen in presence of half-moon.

May 2. $8^h\ 30^m$.

R.A. $16^h\ 3^m\ 50^s$, Decl. $+52°\ 59'$.

Fig. 2.

Fig. 3.

Tail not quite so conspicuous but the nucleus bright and sparkling. Comet was also well seen after moonrise, three nights after full.

May 11. $9^h\ 0^m$.

R.A. $15^h\ 29^m\ 10^s$, Decl. $+56°\ 9'$.

Very clear, and comet looked brighter. More of the tail seen and the nucleus very sparkling.

June 10. $9^h\ 35^m$.

R.A. $13^h\ 21^m\ 0^s$, Decl. $+56°\ 57'$.

Fig. 4.

Fig. 5.

First observation after long period of clouds and rain. Comet fainter, but easily seen in the 3-inch finder. Tail traced nearly to edge of half-degree field, and the nucleus almost as bright as at any previous observation.

I trust that my fellow-workers in England and on the Continent have been interested in following this celestial visitant in its favourable pathway across the sky.

May I be allowed to put on record here that this is the twenty-fourth cometary discovery I have been permitted to make? Eleven of these were found with reflectors at the old Red House Observatory, Phelps, N.Y., two with the same instrument soon after my removal here, the 9-inch reflector being set up in the garden pending the installation of the observatory equipment. The remaining eleven comets have been discovered with the 10-inch refractor of this observatory. Comet-seeking is, however, only carried on in the few intervals between other duties, among which is the entertainment of visitors, the Observatory being freely open to the public on every clear night. This explains why most of my Geneva comets have been discovered in the morning sky.

Smith Observatory, Geneva, N.Y., U.S.A.:
1904 *July* 12.

Errata.

Mean Daily Area of Sun-spots for Each Degree of Solar Latitude for each Year from 1874 *to* 1902 *as Measured on Photographs at the Royal Observatory, Greenwich.*

(*Communicated by the Astronomer Royal.*)

The following corrections should be made in the paper bearing the above title, and appearing in the *Monthly Notices*, vol. lxiii. No. 8 :

Page.	Year.	Latitude.	*For*	*Read*
457	1896	$+20^\circ$	2·2	21·5
460	1892	−25	10·8	17·8
,,	,,	−35	0·01	...
,,	,,	−40	...	0·01

Erratum in Mr. Maunder's Paper on the Distribution of Spots in Heliographic Latitude.

Vol. lxiv. p. 758, line 32, *for* $\frac{1}{250}$ *read* $\frac{1}{25}$.

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

APPENDIX TO VOL. LXIV.

[*From Proceedings of the Royal Society, Vol. LXXII.*]

With indication of the original pagination.

No. 1.

CONTENTS.

Page

Professor J. H. Poynting, Radiation in the Solar System: its Effect on Temperature and its Pressure on Small Bodies . . . . . [1]

"Radiation in the Solar System; its Effect on Temperature and its Pressure on Small Bodies." By J. H. Poynting, Sc.D., F.R.S., Professor of Physics in the University of Birmingham. Received June 16,—Read June 18, 1903.

(Abstract.)

Part I.—*Temperature.*

We can calculate an upper limit to the temperatures of fully absorbing or "black" surfaces receiving their heat from the sun, and on certain assumptions we can find the temperatures of planetary surfaces, if we accept the fourth power law of radiation, since we know approximately the solar constant, that is, the rate of reception of heat from the sun, and the radiation constant, that is, the energy radiated at 1° abs. by a fully radiating surface.*

The effective temperature of space calculated from the very uncertain data at our command is of the order 10° abs. Bodies interplanetary space and at a much higher temperature may, therefore, be regarded as being practically in a zero temperature enclosure except in so far as they receive heat from the sun.

The first case considered is that of an ideal earth, more or less resembling the real earth, and it is shown that the temperature of its surface is, on the average, 325°, 302°, or 290° abs. according as we take for the solar constant Ångström's value 4 cal. min., Langley's value 3 cal./min. or a value deduced from Rosetti's work 2·5 cal./min. The lowest value found, 290° abs., is very near the average temperature of the earth's surface, which may be taken as 289° abs. As the earth's effective temperature must, if anything, be below this, and cannot differ much from that of the ideal planet, Rosetti's value for the solar constant, 2·5 cal./min. or $0{\cdot}175 \times 10^7$ ergs./sec., is probably nearest to the true value and is therefore used in the following calculations.

The preceding calculations may be turned the other way. It is shown that, on certain assumptions, the effective temperature of the sun is 21·5 times that of the ideal earth. If we consider that the real earth with a temperature 289° abs. sufficiently resembles the ideal, we get a solar temperature $21{\cdot}5 \times 289 = 6200°$ abs.

The upper limit to the temperature of the surface of the moon is determined and is shown to be 412° abs. when no heat is conducted inwards. But Langley finds that the actual temperature is not much

* W. Wien ('Cong. Int. de Physique,' 1900, vol. 2, p. 30) has pointed out that Stefan's law enables us to calculate the temperature of celestial bodies which receive their light from the sun, by equating the energy which they radiate to the energy which they receive from the sun, and remarks that the temperature of Neptune should be below −200° C.

above the freezing point on the average. This leads us to the conclusion that it is not higher than four-fifths the highest possible value, the reduction being due to inward conduction.

The temperature of a small body, dimensions of the order of 1 cm. or less, but still so large that it absorbs radiation, is shown to be nearly uniform, and at the distance of the earth from the sun about 300° abs.

Under otherwise similar conditions temperatures must vary inversely as the square root of the distance from the sun. Thus Mars, if an earth-like planet, has a temperature nowhere above 253° abs., and if a moon-like planet, the upper limit to the temperature of the hottest part is about 270°.

Part II.—*Radiation Pressure.*

The ratio of radiation pressure due to sunlight to solar gravitation increases, as is well known, as the receiving body diminishes in size. But if the radiating body also diminishes in size this ratio increases. It is shown that if two equal and fully radiating spheres of the temperature and density of the sun are radiating to each other in a zero enclosure, at a distance large compared with their radii, then the radiation push balances the gravitation pull when the radius of each is 335 metres. If the temperature of two equal bodies is 300° abs. and their density 1, the radius for a balance between the two forces is 19·62 cm. If the density is that of the earth, 5·5, the balance occurs with a radius 3·4 cm. If the temperatures of the two are different, the radiation pressures are different and it is possible to imagine two bodies, which will both tend to move in the same direction, one chasing the other, under the combined action of radiation and gravitation.

The effect of Döppler's principle will be to limit the velocity attained in such a chase. The Döppler effect on a moving radiator is then examined and an expression is found for the increase in pressure on the front, and the decrease in pressure on the back of a radiating sphere of uniform temperature moving through a medium at rest. It is proportional to the velocity at a given temperature. The equation to the orbit of such a body moving round the sun is found, and it is shown that meteoric dust within the orbit of the earth will be swept into the sun in a time comparable with historical times, while bodies of the order of 1 cm. radius will be drawn in in a time comparable with geological periods.

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With indication of the original pagination.

No. 2.

CONTENTS.

	Page
Dr. W. J. S. Lockyer, Sunspot Variation in Latitude 1861—1902 . .	[5]
Professor A. Fowler, The Spectra of Antarian Stars in Relation to the Fluted Spectrum of Titanium	[16]
Sir N. Lockyer, Further Researches on the Temperature Classification of Stars	[23]

"Sunspot Variation in Latitude, 1861—1902." By WILLIAM J. S. LOCKYER, M.A. (Camb.), Ph.D. (Gött.), F.R.A.S., Chief Assistant, Solar Physics Observatory. Communicated by Sir NORMAN LOCKYER, K.C.B., LL.D., F.R.S. Received January 16, —Read February 11, 1904.

In a previous communication,* Sir Norman Lockyer and I gave the results of a discussion of prominence observations, and pointed out the necessity of dealing individually with small zones on the solar surface.

In that paper brief reference was made to the law of spot zones, as discovered by Carrington, and corroborated by Spörer, and it was further stated that more modern observations had established these *general* deductions of spot distribution. The words "general deductions" were purposely used, as it was then noticed that there were many anomalies that required explanation.

The object of the present paper is to draw attention to these anomalies, and to give the results that have been deduced from a minute examination of the changes of heliographic latitudes of sunspots from year to year. The present evidence indicates that the law of Spörer, although of great importance, represents only a very general idea of a complicated sunspot circulation.

* "Solar Prominence and Spot Circulation, 1872—1901," 'Roy. Soc. Proc.,' vol. 71, p. 446.

From a valuable series of sunspot observations, made between the years 1853 and 1861, Richard Carrington* was the first to point out that spots had a general drift towards the Equator during a sunspot cycle, or, to use his own words, there was indicated "a great contraction of the limiting parallels between which spots were formed for two years previously to the minimum of 1856, and, soon after this epoch, the apparent commencement of two fresh belts of spots in high latitudes, north and south, which have in subsequent years shown a tendency to coalesce, and ultimately to contract, as before, to extinction." Spörer fortunately took up the work where Carrington left off, and his observations extended over the period 1861—1879. These were published in four different volumes,† and the conclusions at which he arrived practically corroborated those of Carrington. In the last of these publications, Spörer summed up all the observations for the period 1854—1879, and published curves, showing the relation between the sunspot frequency for these years and the variation of the mean heliographic latitude of the spots.

The law of zones, as definitely formulated by Spörer, is as follows‡ :—"Un peu avant le minimum, il n'y a de taches que près de l'equateur solaire, entre $+5°$ et $-5°$. A partir du minimum, les taches, qui avaient depuis longtemps déserté les hautes latitudes, s'y montrent brusquement vers $\pm 30°$. Puis elles se multiplient, un peu partout, à peu près entre ces limites, jusqu'au maximum, mais leur latitude moyenne diminue constamment jusqu'à l'époque du nouveau minimum."

As solar prominences appear on any part of the disc, it was sufficient, in order to trace their distribution, to divide the sun's surface into nine zones of 10 degrees each. Since, however, spots seldom occur above latitude 40°, the width of the zones had to be considerably diminished. For the present inquiry, it was finally decided to group the spots into belts 3 degrees wide, for even zones of 5 degrees in width were found to mask many important characteristics.

The necessity for such narrow zones will be seen from the accompanying figure (fig. 1), in which the yearly distribution of spots is shown for the years 1879—1883, taking zones of 10 degrees, 5 degrees, and 3 degrees in width respectively.

* 'Observations of the Spots on the Sun,' made at Redhill by R. C. Carrington, F.R.S., 1863, p. 17.

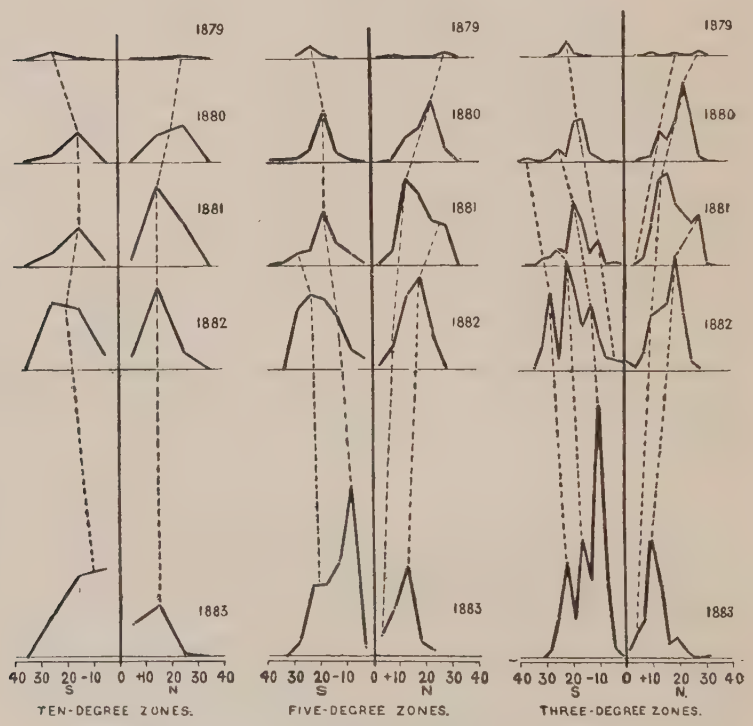
† 'Publication der Astronomischen Gesellschaft,' vol. 13 (Leipzig, 1874); 'Publication der Astronomischen Gesellschaft,' vol. 13. Fortsetzung (Leipzig, 1876); 'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' No. 1, vol. 1, Part I; No. 5, vol. 2, Part I.

‡ 'Comptes Rendus,' vol. 108, p. 486.

In these curves each broad vertical line corresponds to the solar equator, and the scales to the right and left of each represent the north and south latitudes respectively. The heights of the curves above each horizontal zero line indicates the different amounts of spotted area, and the scales of these are so arranged that the curves are all proportional to the spotted area.

The curves themselves are formed by determining the mean spotted

FIG. 1.



DISTRIBUTION OF SUN'S SPOTTED AREA.

FROM 1879—1883.

area for each zone, and plotting each value at the point representing the mean latitude of this zone; these points are then all joined together. Thus, in the case of the 0—10° zone, the mean spotted area is plotted at 5°, 10—20°, at 15°, etc. The other zone divisions are similarly treated, thus, 0—5° is plotted at 2·5°, 0—3° at 1·5°, etc.

In the 10° zone curves here shown there is only one maximum in each hemisphere for the years in question, and these, as indicated by the dotted curves which join them, do not progress gradually towards

the equator, as would probably be the case according to Spörer's law. With 5° zones it is possible to detect the presence of two maxima in one or other of the hemispheres, all of which have a trend towards the equator in succeeding years. Still more detail is displayed in the 3° zones, and here is apparent a spot distribution and movement which is practically masked in the two preceding sets of curves.

The advisability of adopting 3° zones for the present investigation being thus apparent, the whole series of observations from the year 1861—1902 was treated in the above manner, the points plotted and the curves drawn as shown in the figure previously referred to.

This reduction was rendered comparatively easy by the fact that the Astronomer Royal has quite recently published* the values of the amount of sunspot area for each degree of latitude for each hemisphere from the year 1874—1902. For information previous to that date use was made of the detailed observations of the positions and areas of sunspots collected by Spörer in the publications already referred to, and curves for each year were drawn. For this period the curves employed were of a less degree of accuracy than those drawn from the Greenwich reduction, as the number of days of observation throughout a year was not so great.

Advantage was taken of the fact that Spörer's observations and those reduced at Greenwich overlapped during the four years 1874—1877, and a comparison of the curves from each series was rendered possible. The close similarity of these in each case showed that the reduction of Spörer's observations exhibited the chief features of the movements of centres of spot-activity as indicated by the Greenwich curves.

By thus employing Spörer's observations, curves for each of the 42 years from 1861—1902 inclusive were drawn in the manner described above, and these were placed vertically one under the other, like those shown in fig. 1 for the years 1879—1883.

In this way it was possible to trace the varying positions, as regards changes of latitude, of the centres of action, or maxima points of the curves, from year to year, just as was previously attempted in the case of the prominences. These centres of action were then connected by lines passing from one yearly curve to the next. It is worthy of remark that very little difficulty was met with in deciding the maxima points to be joined. There was always, throughout the whole period, a most distinct march of these points individually towards the equator, and the method of placing the curves one beneath the other rendered such movement at once obvious to the eye. There was only one instance where it seemed necessary that a march from lower to higher latitudes ought to be considered. This was in the southern hemisphere, in the years 1889 and 1890 (see Plate [2], Curve A). There

* 'Monthly Notices R. A. S.,' vol. 63, pp. 452—461.

was a small indication of the presence of a spot centre of action in latitude 19° in the former year, while next year the position of the centre of action was in latitude 24°. Since this case was unique, it was considered advisable not to connect these points together, but to leave the centre of action in the year 1889 as an isolated point.

The diagram (fig. 1) not only exhibits some of the types of curves met with, but shows how the various centres of maximum spot-activity were joined up with each other, year by year, for the period of time over which the curves extend, namely, from 1879, the year following a sunspot minimum, to about a sunspot maximum in 1883.

Considering the curves relating to the sun's northern hemisphere, it will be seen that in 1879, the year following a sunspot minimum, when the spots were ending a cycle near the equator, two new outbreaks occurred in latitudes about 20° and 30°.

These two centres of activity moved towards the equator next year, and by 1881 the former had disappeared, while the other rapidly grew in intensity and reached latitude 15°. During this year a new outbreak in latitude 30° made its appearance, and this in the two following years had an equatorial trend.

A somewhat similar occurrence took place in the southern hemisphere, each of the centres of action moving rapidly towards the equator.

It is interesting to note the rapid growth and decay of these centres of action, an example of which is shown commencing in 1879 in latitude 28° in the northern hemisphere.

Attention may particularly be drawn to the three prominent maxima of the curves for the southern hemisphere in the years 1882 and 1883, which indicate that at this period there were three definite centres of spot action in existence.

In order to bring within a small compass the results of the above analysis for the whole period of investigation (the above-mentioned forty-two curves, although drawn close together on a small scale, cover a strip of paper 5 feet in length), a method was adopted similar to that employed in the case of the prominence reduction.*

In the accompanying plates the two sets of curves marked A indicate for each hemisphere the changes in the positions of these centres of spot activity from year to year plotted at equal intervals of a year. The striped portion is deduced from Spörer's observations, and the remainder from the Greenwich reductions. These lines have been proportionally thickened to indicate approximately the relative amount of spotted area at these centres of action, or, in other words, the heights of the maxima points on the yearly curves. These curves thus indicate for each year the positions, as regards latitude, of the particular zones

* 'Roy Soc. Proc.,' vol. 71, pl. 6.

in which the centres of spot activity occur, and give an idea of the movements of these centres during each sunspot cycle.

In this paper these curves have been called "spot-activity tracks," but it is important to point out that this term is not necessarily applied to the proper motion of any individual spot, but simply to the changes of position of the regions in which they are most numerous. As, therefore, the term "spot-activity tracks" represents the different positions of the regions of greatest spot-activity, so "prominence-activity tracks" may be employed to indicate the equivalent variations as regards the prominences which were shown in a previous paper.*

These "spot-activity tracks" have possibly a terrestrial equivalent in the variations from year to year of the positions of the "Zugstrassen," or cyclone tracks of Köppen, it having been found that cyclones in general, which move in the direction of the great mass of air carried by primary currents, have a strong tendency to pursue somewhat the same tracks according to the place of origin.

For the sake of comparison, curves B, C, and D in each plate have been added. Curves B show the variations of the mean heliographic latitude of the total spotted area for each hemisphere as determined and described in a previous paper.†

Curves C illustrate the distribution and changes of position of the centres of prominence activity. These curves are somewhat different to those previously published,‡ being so arranged that they form a continuous series from the year 1870. The small circles in the years 1870—1871 represent Respighi's observations, the curves from 1872—1881 those of Tacchini, and the remainder, up to the year 1902, Ricco and Mascari's observations. The dotted curves previous to 1870 are intended only to give a rough idea of the prominence variations based on a repetition of the observations of 1872—1885.§ The last curves, namely, those marked D in the plates, represent the variation from year to year of the total spotted area on each hemisphere of the sun, and special attention was drawn in a previous publication‖ to the great differences between the two hemispheres at the times of sunspot maxima. The vertical broken and continuous lines indicate the epochs of sunspot minima and maxima as determined by combining the amount of spotted area on both hemispheres of the sun.

Reverting now to the curves marked A, which form the special subject of the present paper, the following *general* deductions may be made :—

1. From sunspot minimum to minimum there are three, but generally

* 'Roy. Soc. Proc.,' vol. 71, p. 446.
† 'Roy. Soc. Proc.,' vol. 71, p. 449.
‡ 'Roy. Soc. Proc.,' vol. 71, pl. 6 and 7.
§ 'Monthly Notices R. A. S.,' vol. 63, No. 8, p. 484.
‖ 'Roy. Soc. Proc.,' vol. 71, p. 246, footnote.

four, distinct "spot-activity tracks," or loci of movements of the centres of action of spot disturbance.

2. The first appearance of each of these "spot-activity tracks" occurs generally between a sunspot minimum and the following maximum. After about the epoch of maximum generally no new "spot-activity tracks" of large magnitude are commenced.

3. Their first appearance is mostly in higher latitudes than 20° in each hemisphere.

4. They are faintly indicated at first, become more prominent and distinct, and finally thin out and fade away.

5. They all fade away in regions close to the equator.

6. There seems to be a tendency for each successive "spot-activity track" to make its appearance in latitudes higher than the one preceding it.

7. At, or a little after, the time of sunspot maximum there is also a tendency for each "spot-activity track" to retain its latitude for a short time.

In the light of these curves it is interesting to analyse those formed by plotting the mean yearly heliographic latitude of spotted area for each hemisphere: these are given in the accompanying plates (Curves B). These latter curves represent the drift from year to year of the mean heliographic spot latitude, and illustrate Spörer's "Law of Zones." It will be noticed that each commences in high latitudes about the time of sunspot minimum, and gradually approaches the equator until the epoch of the following minimum, when a new cycle in high latitudes recommences.*

An important point to be noticed about this series of curves is that each is of a *wavy* nature. This peculiarity is clearly shown even in the plate illustrating Spörer's reduction† which covers the period 1854—1880. There the curves, representing the mean spotted area and the mean heliographic spot latitude for both hemispheres combined, were compared, and Spörer pointed out some anomalies between these mean curves and those formed by joining the actual points of observation. So conspicuous were these anomalies at one epoch (even after many of the peculiarities had been lost by combining the two hemispheres instead of treating them singly), that he drew attention to them in the following words‡: "Nun sieht man an den Beobachtungspuncten, welche bei der Breitencurve eingetragen sind, dass die aus specieller Rechnung hervorgehende Curve *ebenfalls eine*

* These curves should overlap, but the unit of time, namely, the year, here employed, masks this feature.

† 'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 2, Erstes Stück, No. 5, Tafel 32.

‡ 'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 2, Erstes Stück, No. 5, p. 81.

Welle liefern würde, und zwar hätte diese ihre grösste Erhebung gegen Ende des Jahres 1875." As will be seen from a further quotation from the same page, Spörer distinctly noticed subsidiary increases of spotted area and a reversion of spots to higher latitudes, and this drew from him the conclusion that the epoch of the following sunspot minimum would be late.

He wrote (page 81), "die Ursache, welche eine Erhebung der Breitencurve bewirkte, d. h. welche veranlasste, *dass in höheren Breiten als vorher Flecke entstanden*, dadurch auch Veranlassung gewesen ist, dass wiederum Vermehrung der Flecke eintrat und damit auch das Flecken-Minimum für längere Zeit verzögert wurde."

Again, from the solar observations made at the Kalócsa Observatory during the years 1880—1884, both years inclusive, Dr. Braun* depicted in a graphic manner the progressive changes in the mean heliographic latitude of the spots during this period, and drew attention to the differences between the mean curve and that passing strictly through the points of observation (fig. 2). The mean curve he found

Fig. 2.

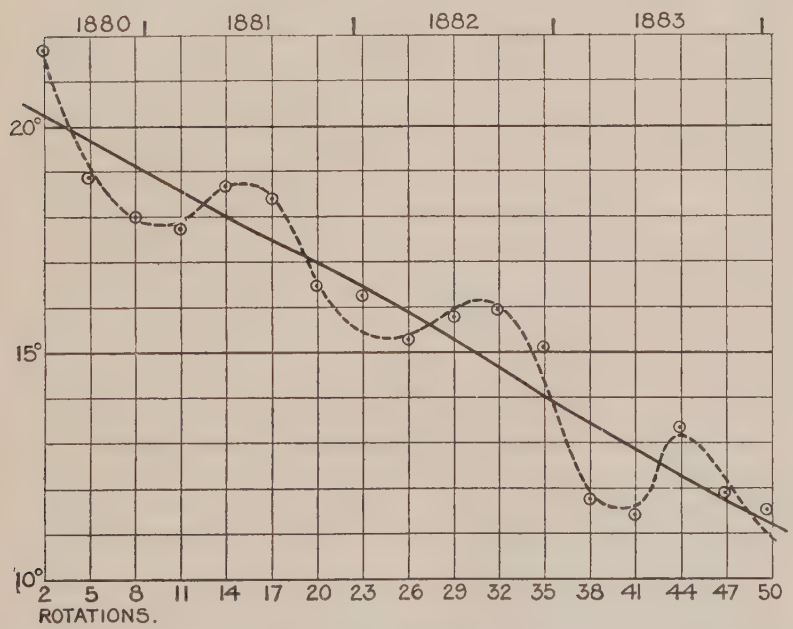


Diagram to illustrate for the years 1880—1883 the differences between the curve showing the decrease of the mean heliographic latitude for the entire spotted area of both hemispheres taken together (continuous curve), and that obtained by a less smoothed curve (dotted) passing through the points of the actual observations.

* 'Berichte von dem Erzbischöflich Haynaldschen Observatorium zu Kalócsa in Ungarn,' von Carl Braun, S.J. Münster i. W., 1886.

to continually approach the equator, but superposed upon the line of uniform descent was a series of minor oscillations. In this connection he wrote:* "Die Spörer'sche Entdeckung der in jeder Periode auftretenden Annäherung der Flecken-Zone gegen den Aequator findet somit in unsern Beobachtungen eine unmisskennbare Bestätigung. Allerdings sind die Zeichnungen nicht durchaus von demselben Gehilfen ausgeführt worden, und dieser Umstand mag einigen Einfluss in Bezug auf diese Wahrnehmung haben . . . Sehr auffallend erscheint eine gewisse secundäre periodische Schwankung der mittleren Breite mit einer Periode von etwa 1 Jahr und einer Amplitude von reichlich 2 Graden . . . Diese mag wohl einem Zufall zuzuschrieben sein, welche nur während dieser vier Jahre obwaltete, vielleicht auch mit dem Wechsel der Zeichner in Zusammenhang steht. Doch wäre es immerhin von Interesse, dass diese Wahrnehmung durch die Discussion anderweitiger Beobachtungen geprüft und eventuell näher untersucht würde."

The present investigation seems to throw light on these peculiar changes of curvature shown by the mean heliographic latitude curves. These latter (Plates [1] and [2], Curves B) are individually really nothing more than the *integration* of the corresponding Curves A. Every change of curvature in Curves B is due to either the outburst of spots in another "spot-activity track" or by one "spot-activity track" becoming more intensified in relation to another, or lastly by the extinction of a "spot-activity track" as the equator has been reached as shown in the Curves A.

To illustrate this, let the curve for the mean heliographic spot latitude in the southern hemisphere (Plate [2], Curves B) beginning in the year 1879 be considered. This is practically the period referred to above by Dr. Braun.

At this time there is only one "spot-activity track" (latitude 22°) in existence, as shown in Plate [2], Curve A; so Curve B consequently commences in the same latitude. By the next year the "spot-activity track" (Curves A) has reached latitude 17°, and a new one has made its appearance in latitude 25°. Curve B, therefore, takes the mean position of about 20°, when allowance has been made for the difference of intensity of these two tracks.

In the following year 1881 both these "spot-activity tracks" have approached nearer the equator, but another has appeared in latitude 25°, so that the mean latitude for the whole hemisphere has only slightly changed.

By the year 1882 still another "spot-activity track" has come into existence in latitude 28°, while the first "spot-activity track" mentioned

* *Ibid.*, p. 83.

above has vanished. The mean latitude for the whole hemisphere, as is indicated in Curve B for this epoch, is increased to latitude 20°. After this all three "spot-activity tracks" approach the equator and Curve B does the same, but owing to the relative changes in the amount of the spotted area in each of these "spot-activity tracks" as indicated by their thickness, the mean heliographic latitude curve suffers another change of curvature in 1885. In a similar way the various changes of curvature in all the other curves (Curve B) can be accounted for.

Particular attention has been drawn to the fact that about the times of sunspot maxima there is considerable spot activity in the highest spot latitudes, which according to Spörer's law would not be expected.

The following extract expressing the impressions of Messrs. De La Rue, Stewart and Loewy on this point is therefore of interest, since it shows that such activity at the maximum of 1871 was even remarked as long ago as 1872.* "A striking feature of last year's observations seems to have been the occurrence of groups in comparatively high latitudes, especially in the southern solar hemisphere; a group observed between March 21 and 23 had the almost unprecedented high latitude of 43°, while latterly, towards the end of the year, several groups in almost as high a latitude have repeatedly made their appearance."

The Wilna observers also drew attention to the high latitudes of some spots about this maximum period, 1869—1871, as can be gathered from the following extract.†

"Generally speaking, during the last three years, about the last maximum, the spots were most distant from the equator; five spots were observed near latitude 38°; three about latitude 40—43°; one at $51\frac{1}{2}$° latitude, . . ."

A word may finally be said as to the relationship between the curves representing the "spot-activity tracks" (Curves A), and those indicating the "prominence-activity tracks" (Curves C). As was pointed out in a previous communication‡ the general drift of the prominence activity is from low to high latitudes.

It is of interest here to note that from the time of a sunspot minimum when the "prominence-activity tracks" are approaching more rapidly high latitudes, up to about a sunspot maximum when they reach their highest positions, nearly all the "spot-activity tracks" come into existence. Further, the nearer the "prominence-activity tracks" approach the poles the higher in latitude do these "spot-activity tracks" also occur, and this is the case for each hemisphere of the sun separately.

* 'Monthly Notices R. A. S.,' 1872, vol. 32, p. 225.

† 'Report of the Committee on Solar Physics,' 1882, p. 155.

‡ 'Roy Soc. Proc.,' vol. 71, p. 452.

What the actual connection between these two different systems of currents is, it is not possible yet to say, but these facts suggest a very close relationship.

In conclusion, I wish to express my thanks to Mr. T. F. Connolly, computer in the Solar Physics Observatory, for his assistance in making the reductions and drawing the numerous curves.

Conclusions.

The result of the investigation leads to the following conclusions:—

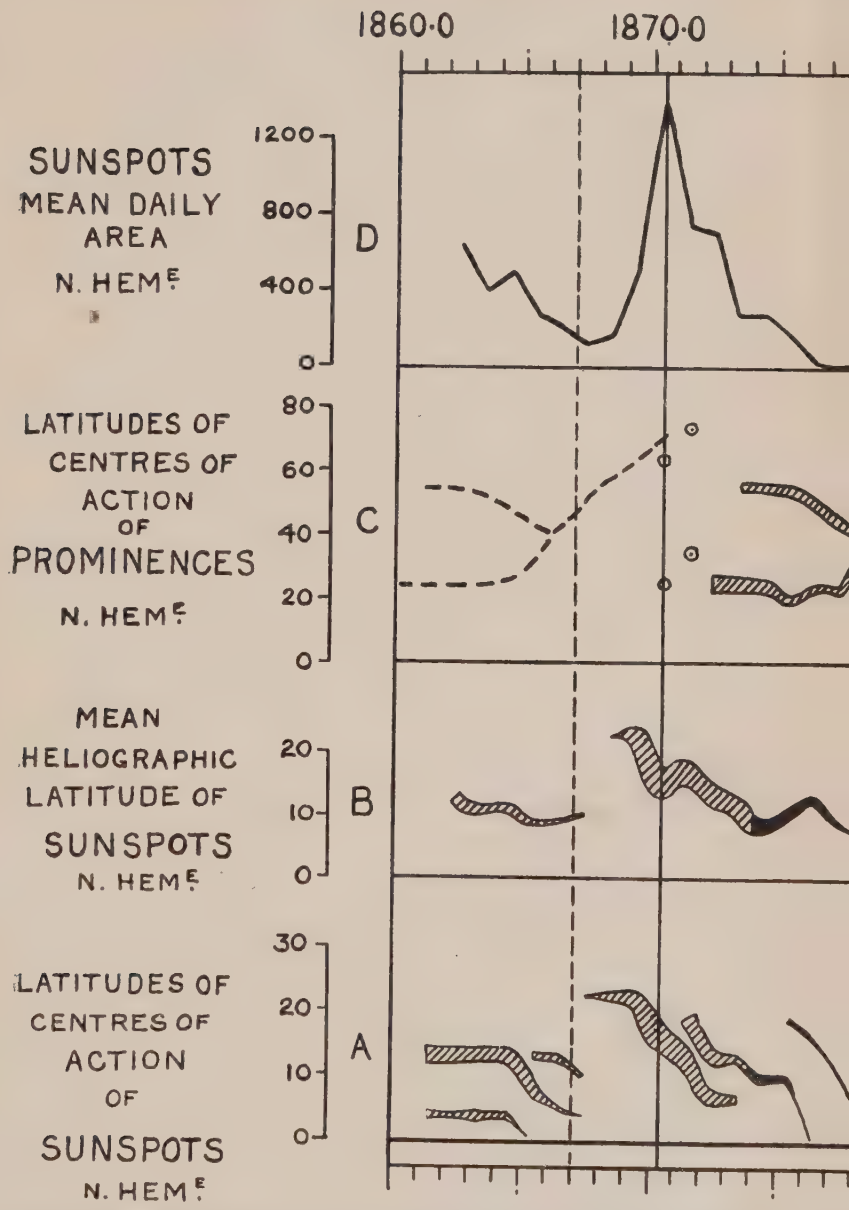
1. Spörer's law of spot zones is only approximately true, and gives only a very general idea of sunspot circulation.

2. Spörer's curves are the integrated result of two, three and sometimes four "spot-activity track" curves, each of the latter falling nearly continuously in latitude.

3. Spörer's, and many other previous reductions have indicated the peculiar "wavy" nature of the integrated curve, which peculiarity is here shown to be for the most part real and not due to errors of observation, etc.

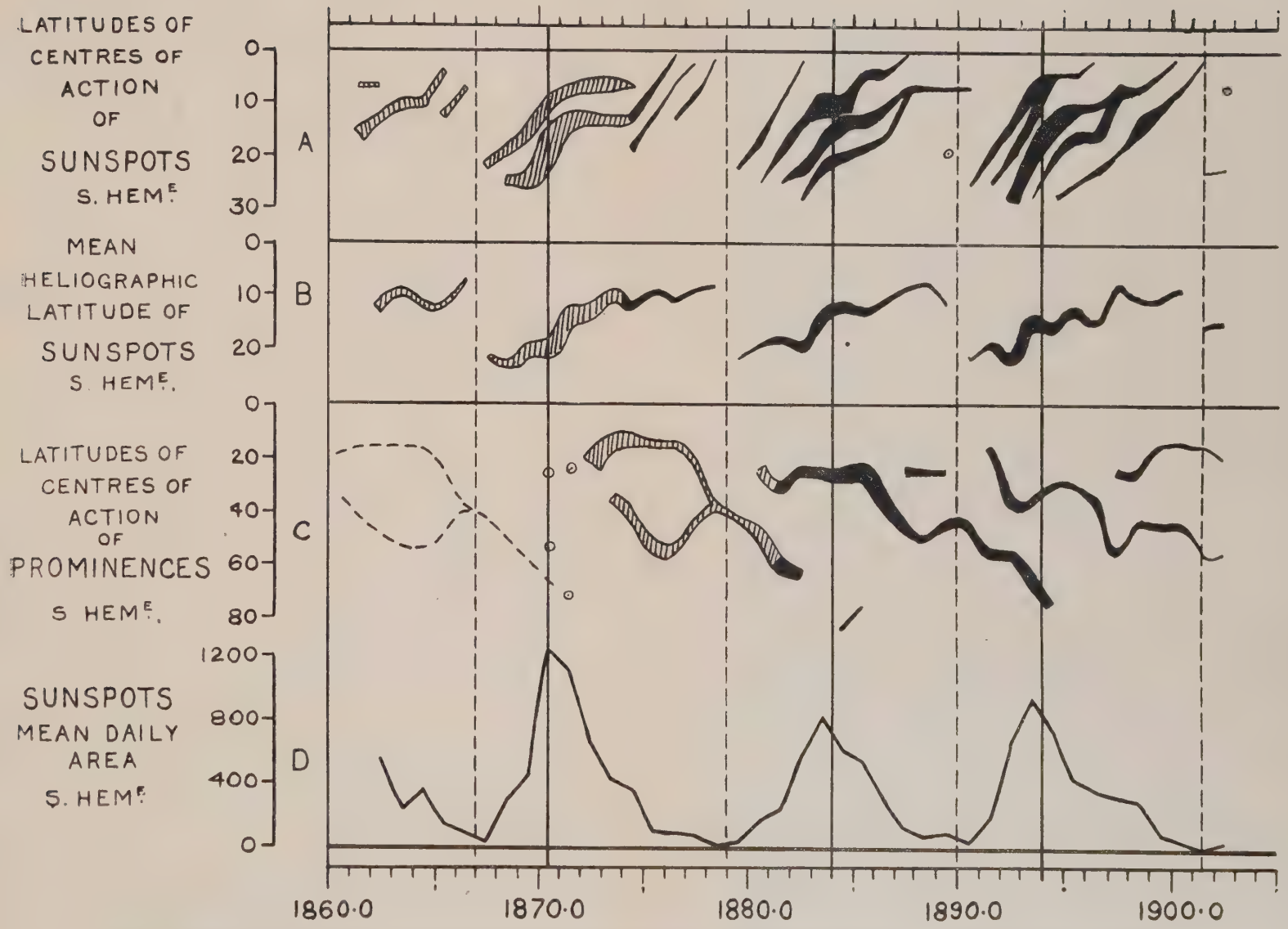
4. Outbursts of spots in high latitudes are not restricted simply to the epochs at or about a sunspot minimum, but occur even up to the time of sunspot maximum.

5. The successive commencement of the "spot-activity tracks" in higher latitudes between a sunspot minimum and maximum seems to be closely related to the "prominence-activity tracks" at these periods.



Curves showing the relation between the positions of the centres of action of Sunspots o
activity Tracks" (C), the mean heliographic latitude of Sunspots north of the equa
of the sun.

Note.—The continuous and broken vertical lines represent the epochs of sunspot m
whole solar disc



Similar curves to those on Plate [1], only in this case the southern hemisphere of the Sun is referred to. Vertical lines same as Plate [1].

"The Spectra of Antarian Stars in Relation to the Fluted Spectrum of Titanium." By A. Fowler, A.R.C.S., F.R.A.S., Assistant Professor of Physics at the Royal College of Science, South Kensington. Communicated by Professor H. L. Callendar, F.R.S. Received February 18,—Read March 3, 1904.

The distinguishing feature of the spectra of the Antarian Stars* is the system of apparently dark flutings, sharp towards the violet and fading off towards the red end of the spectrum. The principal flutings are well seen in Antares, but they are more strongly developed in the spectra of α Herculis and o Ceti, in which stars additional details are also seen. These flutings have not hitherto received a definite chemical interpretation, and it has been uncertain, owing to the possibly misleading effects of contrast, whether the spectrum was to be regarded as one consisting wholly of absorption flutings fading towards the red, or as one partly consisting of emission flutings fading in the opposite direction.

The purpose of the present communication is to state the nature of the evidence which indicates that the spectrum is essentially an absorption spectrum, and that the chief substance concerned in the production of the flutings is titanium, or possibly a compound of that element with oxygen.

The first indication of this result was the striking general resemblance of the titanium flutings, as seen in photographs recently obtained, with the stellar flutings, both as to relative intensity and apparent position (Plate [3]). The interspaces between the flutings, as they appear on a negative, in some cases also strongly recall the corresponding bright spaces in the stellar spectra.

* Secchi's Type III; Vogel's Class III*a*.

The most extensive series of visual observations of the Antarian stars were made by Vogel* and Dunér† many years ago, and for the part of the spectrum extending from near D to the extreme red, no other measurements have yet been published. For the region more refrangible than D, however, wave-lengths derived from photographs are available, the most complete statements of these being due to Father Sidgreaves‡ and Mr. Stebbings.§ The individual results given by different observers vary considerably: visual observations are difficult, and, in the case of photographs taken with prismatic cameras, errors doubtless arise through the lack of suitable reference lines. There is also some difficulty in deciding where a fluting actually commences. The evidence in favour of a titanium origin for most of the flutings, however, depends on such a large number of coincidences that it is almost independent of a very precise knowledge of wave-lengths.

The flutings in question come out in the arc spectrum of titanium oxide, if the precaution be taken to provide a liberal supply of material and to use a very long arc, taking care also that the image of the "flame" is projected on the slit of the spectroscope. They are also seen in the arc spectrum of the chloride under similar conditions. Numerous lines accompany the flutings produced in this manner and some of the details are consequently masked or not recognized without careful study of the photographs.

So far the flutings have not been very successfully produced in the oxyhydrogen flame; they are visible in the flame spectrum of the fumes from the chloride, but their observation is difficult on account of the bright continuous spectrum.

The best representation of the flutings has been obtained by passing a spark, without jar, through the fumes of oxychloride which rise from the chloride of titanium on exposure to air. Under these circumstances the lines which appear are not numerous, and some of the secondary flutings which are masked by lines in the spectrum of the flame of the arc are readily detected, in spite of the continuous spectrum which is also present. The few lines which do appear in this spectrum are probably low temperature lines which may be found of special importance in the cooler stars.

Photographs have been taken over the region C to K, the instrument employed being one built up on the Littrow principle, having one prism of 60°,‖ and a 2-inch objective of 40 inches focal length, giving a linear dispersion from D to K of 5 inches. Wave-lengths were

* 'Beobachtungen zu Bothkamp,' vol. 1, p. 20, etc.

† 'Sur les Etoiles à Spectres de la Troisième Classe'; "K. Sven. Vet.-Akad. Hand.," vol. 21, No. 2, 1884.

‡ 'Monthly Notices, R.A.S.,' vol. 58, p. 344; vol. 59, p. 509.

§ 'Lick Observatory Circular,' No. 41, May, 1903.

‖ Lent by the Government Grant Committee.

determined in the usual manner by micrometric measurements of the photographs, using reference lines of titanium and iron, and calculating by the Cornu-Hartmann formula; though only provisional, they are probably not greatly in error.

It is instructive first to make a comparison between the more conspicuous flutings and those recorded visually in the stars by Vogel and Dunér. Details of the measurements are given in Table I, but reference should also be made to Plate 6, in which Dunér's drawing of the spectrum of α Herculis, as seen with a spectroscope of small dispersion, is compared with a negative of the titanium flutings, as they appear in the "arc" spectrum of titanium oxide.

Table I.—Comparison of Titanium Flutings with Visual Observations of the Spectra of Antarian Stars.

Titanium flutings.		Antarian flutings (more refrangible edge).	
Wave-length.	Visual intensity.	Wave-length.*	Dunér's number.
7055	10	..	Out of range.
..	..	6493	1
6162·5	10	6164	2
..	..	5862	3
5604·5	8	5596	4
5447·0	10	5453	5
5241·0	5	5243	6
5167·5	10	5169	7
4955·1	8	4960	8
4761·6	7	4769	9
4584·3	5	4608	10

It will be seen be seen that eight of the ten bands recorded by Vogel and Dunér agree within the possible limits of error with the flutings of titanium, and it is to be noted also that the only one of the principal titanium flutings which is not represented in the stellar spectrum is out of range in the extreme red. The origin of the two outstanding bands at 5862 and 6493 has not yet been ascertained. There are traces of titanium flutings near their positions, but they seem inadequate to account for two such distinct bands as those drawn

* The wave-lengths given are the means of Vogel's and Dunér's measurements, corrected to Rowland's scale (Scheiner's 'Astronomical Spectroscopy,' p. 301). For bands 5, 7, 8, 9, 10, the means of the wave-lengths derived from photographs by Lockyer, Pickering, Sidgreaves and Stebbings are respectively 5448, 5165, 4954, 4761, and 4584 (see Table II).

Table II.—Comparison of Titanium Flutings with Photographic Spectra of Antarian Stars.

Flutings of Ti (Fowler).*		Flutings in stars (Stebbings).		Flutings in *o* Ceti (Sidgreaves).		Remarks.
λ.	Intensity.	λ mean of five stars.†	*o* Ceti.	λ.	Intensity.	
			4313·4			
4352·9	3	..	4352·7	4352	7	
4395·2	3	..	4395·0	4395	5	Masked by lines in arc spectrum.
4422·0	2	4421·5	4421·5	4421	4	" " "
4437·0	3	..	..	..	..	Masked in arc spectrum. Sidgreaves notes a "wide line" at 4436.
4461·9	4	..	4462·1	4460	6	Head well defined.
4505·0	4	..	4504·8	4504	6	Head not very well defined. Not recognised in arc spectrum.
4548·4	3	..	4547·9	4546	5	Head apparently strengthened by a line at 4548·9.
4584·3	6	4584·4	4584·1	4583	10	Beginning of Dunér's band 10, λ 4585 Lockyer,‡ 4586 Pickering.§ Head has the appearance of a double line.
4626·4	6	4626·3	4625·8	4625	8	Head well defined, and has the appearance of a double line.
4667·8	5	4667·6	4668·6	4669	9	" " " " "
4714·5	3	4714·1	4713·2	4714	4	Head not sharply defined.
4738·0	2	4737·1	..	4736	3	Possibly only an ill-defined line which appears in "chloride" spark, but not in the arc.
4761·6	7	4761·0	4759·0	4758	10	Beginning of Dunér's band 9, λ 4763 Lockyer, 4762 Pickering. Head sharply defined, and has the appearance of a double line.
4805·6	7	4804·6	4803 2	4803	6	Head appears as a double line.
4842·0	1	..	4841·8	4842	8	A feeble brightening seen only in best photographs; it is not the Ti line λ 4841·0.
4848·6	5	4848·4	..	..	..	Head appears as a double line.
4894·0	2	..	..	4892	3	Head indefinite.

4955·1	8	4954·5	4953·1	4951	10	Beginning of Dunér's band 8, λ 4958 Lockyer, 4954 Pickering. Head sharply defined; a line at 4957·8 possibly forming part of a double head.
5002·8	4	..	..	4998	9	Head rather indefinite; not clearly distinguished in arc. Lines at 4981·9, 4991·2, 4999·7, 5007·4, 5014·4.
5050·5	2	..	..	5046	6	Head rather indefinite; not clearly distinguished in arc.
				5074	3	
				5098	4	
				5135	3	
5167·5	10	5165·8	5165·9	5162	10	Beginning of Dunér's band 7, λ 5165 Lockyer, 5168 Pickering. Head very sharply defined and perhaps double with 2nd head at 5169·8.
5241·0	5	..	..	5237	8	Beginning of Dunér's band 6. Begins with a line which is relatively stronger than in the arc spectrum.
5308·0	3	..	5307·2	5306	7	
5356·6	4	..	5357·7	5356	6	
5407·0	1	..	..	5406	2	
			5438·3			
5447·0	10	5446·8	5446·8	5447	10	Beginning of Dunér's band 5, λ 5455 Lockyer, 5445 Pickering. Head very sharply defined.
5497·5	5	5496·8	5496·9	5498	5	Head well defined.
5604·5	8	..	..	5597	8	Beginning of Dunér's band 4. There are strong lines near 5598, 5630, 5662, 5708, which, with small dispersion, might appear to be the heads of the adjacent flutings. Among other details within this group, Sidgreaves notes "bands" at 5603 and 5642, and a "wide line" at 5667.
5636·3	6					
5668·4	5	..	..	5660	7	
5713·9	3	..	..	5709	3	
5760·9	5	..	..	5756	8	Head well defined } Among the details in this region Sidgreaves notes "bands" at 5761, 5808, and 5845.
5811·0	5	..	..	5804	8	,, ,,
5847·2	3	..	..	5840	8	,, ,,

* As seen in spark without jar through fumes from titanium chloride; they are also seen in the arc unless otherwise stated.

† α Herculis, ρ Persei, β Pegasi, α Orionis, α Ceti.

‡ 'Phil. Trans.,' A, vol. 186, 1893, p. 702.

§ 'Annals Harv. Coll. Obs.,' vol. 28 Part 1, p. 8.

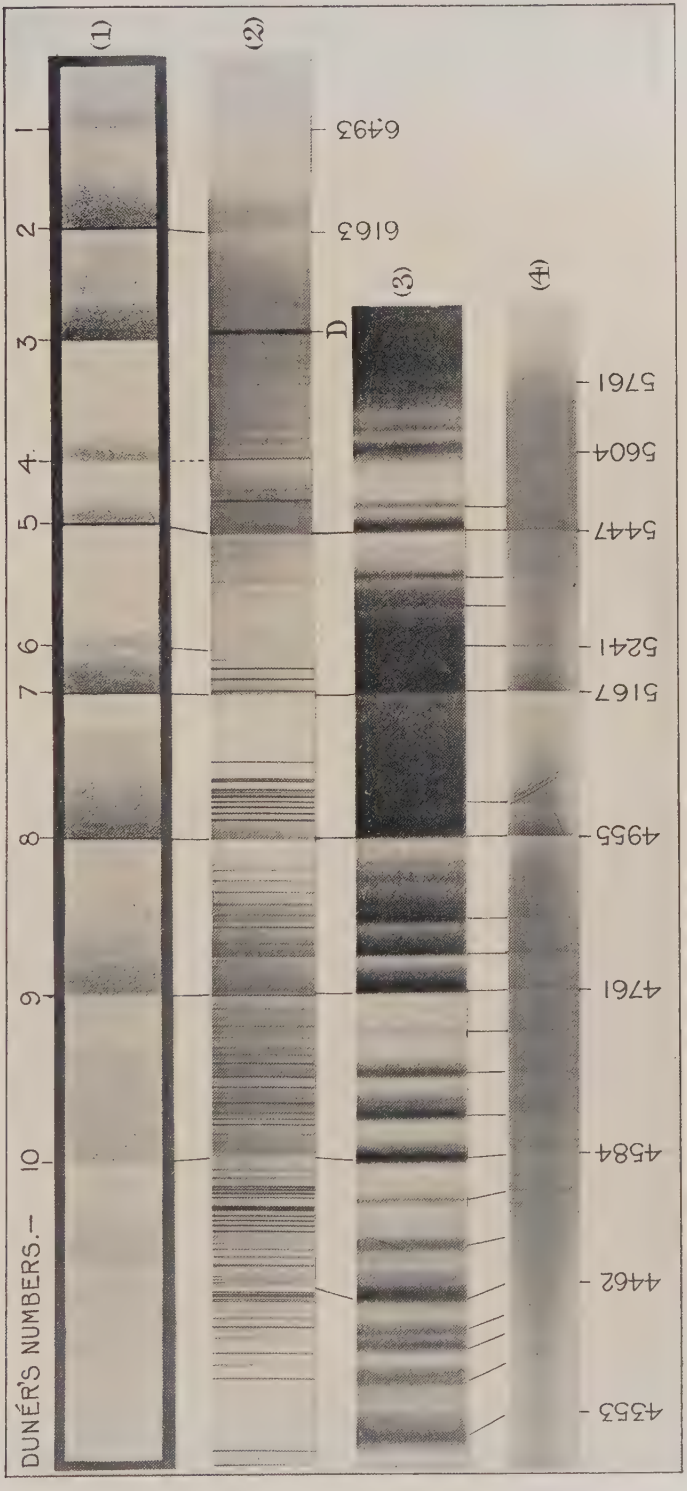
by Dunér. The association of vanadium with titanium in the spectra of sun spots suggested that they might be due to the former element, but this does not appear to be the case. The strongest fluting of vanadium is near 5472, and there is no certain evidence to show the presence of this fluting in the Antarian type of spectrum.

The evidence for titanium in the case of the remaining flutings, however, is enormously strengthened by a discussion of their structure and by extending the comparison further into the violet. Photographs of the stellar spectra, especially those of o Ceti and α Herculis, show that some of the principal flutings are composite, Dunér's band 10, for example, containing, according to Sidgreaves, four distinct flutings separated by intervals of about 44 tenth-metres, each of which is weaker than the one which precedes it on the more refrangible side. A precisely similar structure is found in the case of the titanium flutings, and a comparison of wave-lengths indicates that the various components occupy the same positions as those in the stars, so far as the available measurements permit the test to be applied. For this comparison (Table II) the wave-lengths derived from photographs by Father Sidgreaves and Mr. Stebbings are utilised. The relation may also be gathered by inspection of the reproductions of the photographs given in Plate [3], that of o Ceti having been very kindly placed at my disposal by Father Sidgreaves. Not all the details of the negatives, however, can be brought out in the reproductions, and the relative dispersions are not exactly the same.

It will be seen from the table that the details of the titanium flutings are reproduced with remarkable fidelity in the stellar spectra, and more especially in o Ceti. In the latter spectrum the number of flutings recorded is slightly greater than in the case of titanium, but it is by no means certain that every detail of the titanium spectrum has yet been photographed. It is possible also that some of the features described as flutings in the stellar spectrum may be groups of lines, and in at least one instance (4437) a fluting has been classed as a "wide line."

The points of difference are very slight, and are mostly in the less refrangible part of the spectrum, where the reductions of the stellar spectra present the greatest difficulty. There is a peculiar displacement of the fluting 4848 to λ 4842 in the spectrum of o Ceti, which may possibly be due to the superposition of a fluting or group of lines of undetermined origin; or, it may be that the feeble maximum observed at 4842 in titanium is strong enough in this spectrum to account for the apparent shift. There is also some uncertainty in connection with the complicated groups of flutings and lines extending from 5598 to D, which need further investigation in the stellar spectra with instruments of greater dispersion.

The general agreement is nevertheless such as to leave no reason-



(1) α Herculis (Dunér). (2) Titanium in flame of arc.
(3) o Ceti (Stonyhurst). (4) Titanium in spark without jar.

able doubt that titanium is the main factor in the production of the dark flutings which characterise the Antarian group of stars.

This explanation of the dark flutings suggests that the appearance of bright flutings in the Antarian spectrum arises chiefly from effects of contrast. It does not, of course, exclude the possibility of the presence of bright flutings, such as might be indicated by local brightenings which are not exactly in coincidence with the edges of dark flutings.

Whether the absorption flutings are produced by the vapour of titanium or by that of the oxide has not yet been completely determined. As already pointed out, the flutings may be obtained either from the oxide or the chloride, but as the latter so readily unites with oxygen on exposure to air, it furnishes no evidence against the supposition that the flutings are due to the oxide.

The author has pleasure in acknowledging the very able assistance which has been rendered in the experimental work involved in this investigation by Mr. F. W. Jordan, B.Sc., Teacher in Training in the Department of Astronomical Physics, Royal College of Science.

DESCRIPTION OF PLATE [3].

1. Visible spectrum of α Herculis, as drawn by Dunér.
2. Flutings of titanium, as they appear in the spectrum of the "flame of the arc," when charged with titanium oxide.
3. Photographic spectrum of o Ceti, from a photograph taken at the Stonyhurst College Observatory, November 29, 1897.
4. Flutings of titanium, as they appear when a spark, without jar, is passed through the fumes which rise from titanium chloride on exposure to air.

(*Note.*—The coincidences cannot be very exactly shown in this manner, on account of the differences of dispersion of the three instruments with which the spectra were recorded.)

" Further Researches on the Temperature Classification of Stars." By Sir Norman Lockyer, K.C.B., LL.D., F.R.S. Received January 30,—Read February 18, 1904.

Contents.

		PAGE
1.	Historical Review	227
2.	Aims and Conditions of the present Research	229
3.	The Observational Conditions	230
4.	Description of the Instrument used	231
5.	Method of Work	231
6.	Description of the Photographs	233
7.	Discussion of the Photographs	235
8.	Conclusions	237
9.	Description of Plates	238

1. *Historical Review.*

In my first Bakerian Lecture in 1873 I dealt with the question of the spectra of stars, and pointed out that the facts accumulated up to that time by Rutherford and others led to the view that in the reversing layers of the sun and stars various degrees of dissociation are at work.

I also suggested that the stellar evidence indicated that one of the results of dissociation temperatures could be to " prevent the coming together of atoms which at the temperature of the earth, and at all artificial temperatures yet obtained here, compose the metals, the metalloids, and compounds."*

In a subsequent communication to the Paris Academy I wrote,† " Il semble que plus une étoile est chaude plus son spectre est simple, et que les éléments métalliques se font voir dans l'ordre de leurs poids atomiques."

This last generalisation rested upon the great preponderance of hydrogen in certain stars, which I classed as hottest on the ground that the blue end of the spectrum was open. Of the spectrum of helium,

* 'Phil. Trans.,' vol. 164, p. 479.

† 'Comptes Rendus,' vol. 77, 1873, p. 1357.

which I had first observed and named in 1869, we then knew nothing either on the earth or in the stars; the solar line D_3 being its only representative. The question of the relative temperatures of stars became of great importance in relation to the questions thus raised, but it was not till 1892 that I was able to approach it by means of photography. The interval was spent chiefly in researches bearing upon solar and terrestrial changes in spectra when differences of thermal and electric energies were obvious.

In a paper on stellar spectra in relation to temperature, communicated to the Royal Society in 1902,* I gave an account of an attempt at a temperature classification of stars, utilising the fact that an extension of spectra into the ultra-violet is produced by increased temperature, and further that a lower temperature in an atmosphere above a photosphere would increase the absorption in the blue end. The classification arrived at was based on photographs obtained with instruments having prisms and lenses made of glass which has a strong absorbing effect on the ultra-violet rays.

The general results of the discussion was the conclusion that the stars so far considered might be divided into two series, one of ascending, the other of descending temperature. Further, that the classification proposed was justified both by the relative extensions of the spectra into the ultra-violet and by the temperature sequence of the few typical lines then available for study.

By 1899, laboratory work on the spectra of different substances under different conditions, and the discovery of a terrestrial source of helium by Ramsay, which enabled me to investigate the complete spectrum, had so far facilitated the study of the typical lines in the various stellar spectra, that I felt myself justified in attempting to classify the stars in relation to the chemical sequence revealed by the presence of gaseous and metallic lines, using especially the lines of helium and hydrogen and the "enhanced" and arc lines of the metals. In this way I hoped to be able to test the classification of 1892 based on the relative lengths of spectra.

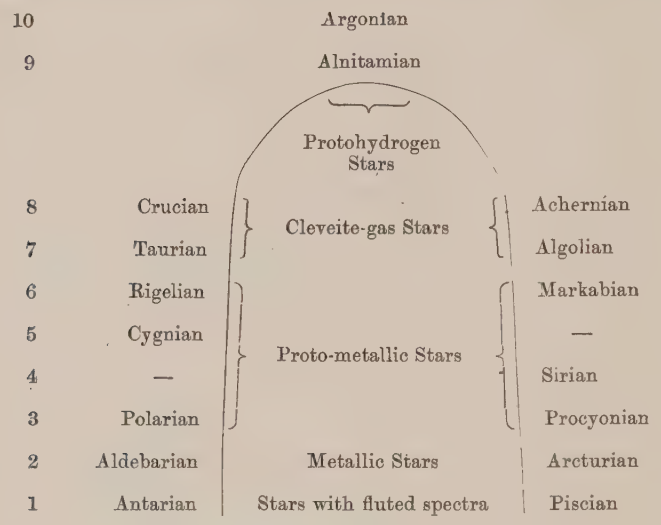
An account of this research was published in the Proceedings of the Royal Society (vol. 65, pp. 186—191, 1899), and ultimately the complete results obtained were included in a "Catalogue of 470 Brighter Stars Classified According to their Chemistry."†

In this catalogue the stars were arranged in sixteen groups along a temperature curve with its apex in the central portion. On the assumption that the chemical changes were due to temperature, including in that term the possible results of electrical energy, the general arrangement of the stellar groups in the order both of ascending and descending temperatures was indicated, the group

* 'Phil. Trans.,' A, vol. 184, p. 688.

† 'Publications of the Committee on Solar Physics,' London, 1902.

containing the hottest stars, on the dissociation hypothesis, being placed at the top of the curve. It will be convenient to reproduce this table here.



There was abundant chemical evidence to show that the mean temperature of the stars occupying the same height on both branches of the curve was not very different, so that we have ten horizons, or stages, of mean temperature indicated in passing from the complete fluted spectra of Antarian-Piscian stars to the simplified line spectra of the γ Argus type.

So far as we could judge from the photographs then available, the chemical changes gave a sequence identical with that desired for the length of ultra-violet spectra in 1892, so that the latter classification was fully justified by the test which had been applied to it.

2. *Aims and Conditions of the Present Research.*

As before mentioned in the work of 1892, the relative lengths of the ultra-violet spectra were determined from photographs secured with instruments having glass optical parts. It was possible therefore to secure still another test by obtaining a new set of photographs using calcite and quartz in place of glass, to enable the far ultra-violet to be obtained and studied. Nor was this all, it seemed of the first importance to utilise not only the length of spectrum in the blue, but the relative brightness of the different parts. What happens regarding the relative brilliancy of the different parts of the spectrum, as well as the extension into the ultra-violet by increased temperature, was very

clearly stated by Sir George Stokes* in 1876, in the following words, "When a solid body such as a platinum wire, traversed by a voltaic current, is heated to incandescence, we know that as the temperature increases, not only does the radiation of each particular refrangibility absolutely increase, but the proportion of the radiations of the different refrangibilities is changed, the proportion of the higher to the lower increasing with the temperature."

This question was also investigated by Melloni and Crova; and in recent years exact determinations of the law of increase have been made by Lummer, Paschen, and others. Melloni showed† experimentally that the maximum radiation moved towards the more refrangible end of the spectrum as the temperature increased. Crova made use of this fact in determining the temperatures of various incandescent light sources, and was one of the first to suggest‡ that the method was applicable to the determination of the temperatures of the sun and stars.

3. *The Observational Conditions.*

The kind of spectroscope to be used and method of observation to be followed were indicated by the following considerations.

In order to utilise the effect of temperature changes to the full it was necessary to record the red end of the spectrum as well as the ultra-violet, as only in this way could the *relative* changes in intensity be recorded, *hence it was desirable to employ only a small dispersion.*

In addition to the natural differences photographed in the ultra-violet, artificial differences due to the absorbing effect of our atmosphere—which, even when clearest, is more or less opaque to the ultra-violet radiations—might be introduced, therefore it was considered advisable, in order to eliminate the effects of atmospheric absorption, to obtain the spectra of any two stars to be compared *whilst they were at approximately the same altitude.* Further, to avoid the many pit-falls to which those who compare photographs taken on plates of unequal sensitiveness, and differently exposed and developed, are liable, it was obviously important that any spectra to be compared should be obtained on the same plate in order to secure identical plate sensitiveness and development.

Again, in order to secure similar optical treatment it was arranged to photograph both spectra near to the optical axis of the camera; thus they are near together in the centre of the plate.

I am sorry to say this work has been considerably delayed by the long time taken in preparing a new camera and optical parts suitable for the research, as above defined, and latterly by a long spell of bad observing weather.

* 'Roy. Soc. Proc.,' vol. 24, p. 353, 1876.
† Taylor's 'Scientific Memoirs,' vol. 1, p. 56.
‡ 'Comptes Rendus,' vol. 87, p. 981.

4. *Description of the Instrument used.*

With regard to the new apparatus, I may state that an objective prism camera (fig. 1), was devised having a 2-inch 30° calcite prism mounted in front of a $2\frac{1}{2}$-inch quartz lens of 18 inches focal length.

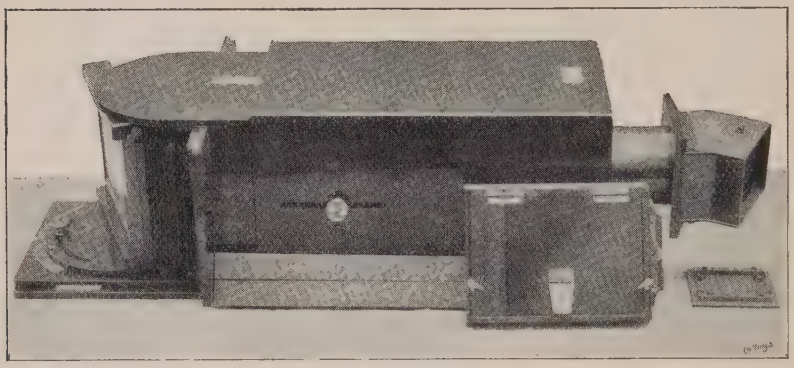


Fig. 1.—Quartz-Calcite Prismatic Camera.

The prism is so cut that its first face is perpendicular to the optic axis of the crystal, and it is arranged that the incident rays are normal to this face. All the rays, therefore, pass through the prism parallel to the optic axis and in this way there is no double refraction.

The whole length of the spectrum is brought into focus in a plane inclined at 42° to the optical axis. The apparatus is attached to the side of an equatorially mounted 6-inch Dallmeyer doublet camera with an angle in declination between the two optical axes equal to the angle of deviation of the calcite prism, so that the Dallmeyer is used as a finder.

Edward's snap-shot isochromatic plates have alone been used, and as they are not sufficiently sensitive for wave-lengths between λ 486 and λ 550 (approx.), there is a break in each spectrum about this region followed by a further portion of the spectrum having its centre about "D." The length of spectrum obtained is such that H_β to H_ϵ is 0·355 inch (9·0 mm.) and from H_ϵ to H_γ 0·165 inch (4·2 mm.).

5. *Method of Work.*

As shown in Table I, there are ten stages or steps of temperature to be investigated, and pairs of stars were selected in order to show the differences between adjacent stages or else the difference between stages widely apart.

Stages 1 and 10 are not available in consequence of the photographic faintness of the Antarian and Piscian stars, and the fact that the only

star as yet known representing the Argonian group is situated in the Southern Hemisphere. The stages already investigated are shown by brackets in the following table.

Table I.

10.		Argonian.	
9.		Alnitamian.	
8.	Crucian.	Achernian.	3.
7.	Taurian.	Algolian.	
6.	Rigelian.	Markabian.	2.
5.	Cygnian.	———	
4.	———	Sirian.	1.
3.	Polarian.	Procyonian.	
2.	Aldebarian.	Arcturian.	
1.	Antarian.	Piscian.	

Thus an Arcturian star (second stage), was compared with a Sirian (fourth stage), and so on. In the case of some stars, *e.g.*, Capella, this was repeated several times, each photograph showing a different comparison.

In securing the photographs an attempt was always made to obtain the pair of spectra with the region between H_β and H_γ of the same intensity in each. This condition is very difficult to fulfil in actual practice owing to the difference of magnitude of the two stars, their difference in declination, and hence in clock rate, and lastly the very important actual differences between the actinism of the two bodies in this region of the spectrum due to their different temperature conditions.

It was also arranged to obtain, whenever possible, the spectra of two stars near together, so that the chances of introducing atmospheric interference due to the different conditions possibly present in various parts of the sky might be reduced to a minimum. In every case where the observer had reason to suspect any change in the atmospheric conditions obtaining during the two exposures, which sometimes extended over a period of $1\frac{1}{2}$ hours, the result has not been included in the discussion.

Thus we have a series of comparison photographs from which all variable conditions except the natural variations in radiation have, as far as possible, been eliminated.

6. *Description of the Photographs.*

Many of the photographs taken are too faint to reproduce well enough to exhibit completely the striking differences shown between the pairs of spectra. I shall therefore content myself by giving a detailed description of each negative (Table II), only reproducing those photographs which are sufficiently dense to plainly show the phenomena under discussion.

Table II.

No. of negative.	Date.	Star.	Stage of temperature.	Type.	Altitude.	Description.
		From Stage 2 to Stage 4.				
19	7.5.03	α Lyræ	4	Sir.	56°	Faintly red, fairly bright to H_γ.
		α Boötis	2	Arct.	57	Intense red, scarcely extends beyond K.
4	29.12.02	β Ursæ Maj.	4	Sir.	59	Red scarcely visible, maximum about λ 400.
		α Ursæ Maj.	2	Arct.	58	Fairly bright red, maximum about λ 460.
14	17.2.03	α Geminorum	4	Sir.	42	Red scarcely visible, maximum about λ 418.
		α Aurigæ	2	Arct.	39	Fairly bright red, maximum about λ 455.
37	21.1.04	α Geminorum	4	Sir.	68	Weak red, maximum about λ 420.
		α Aurigæ	2	Arct.	68	Very dense red; blue maximum commences at F, centre at λ 460, weak beyond λ 388.
		From Stage 4 to Stage 6.				
11	28.1.03	β Orionis	6	Rig.	21	Red not so intense, and ultra-violet much more extended than in Sirius.
		α Canis Maj.	4	Sir.	22	Dense red, centre of maximum about λ 422.

Table II—*continued.*

No. of negative.	Date.	Star.	Stage of temperature.	Type.	Altitude.	Description.
		From Stage 6 to Stage 9.				
35		κ Orionis	9	Alnit.	20°	Although spectrum of Rigel is generally much stronger, that of Alnitam extends as far into the ultra-violet.
		β Orionis	6	Rig.	24	
		Various Intervals.				
34	10.12.03	γ Ursæ Maj.	6	Mark.	78	Faint red, maximum about λ 416, well sustained up to Hθ.
		α Ursæ Maj.	2	Arct.	76	Fairly bright red, maximum at λ 460, rapidly falling off beyond λ 430.
36	14.1.04	η Ursæ Maj.	8	Cruc.	51	Faint red, maximum at about λ 418, bright extension well beyond the end of the Capella spectrum.
		α Aurigæ	2	Arct.	52	Very bright red, maximum at about λ 455, faint beyond K.
23	14.11.03	ε Orionis	9	Alnit.	38	Faint red, centre of maximum at about Hδ. Bright extension far beyond the hydrogen series.
		α Canis Min.	3	Proc.	41	Very bright red, maximum about Hγ, and falls quickly beyond Hκ.
		Extreme Interval.				
33	10.12.03	ε Orionis	9	Alnit.	36	Very faint red, centre of maximum about Hδ, *i.e.*, near the more refrangible end of the Aldebarian spectrum.
		α Tauri	2	Aldeb.	36	Very strong red, centre of maximum about λ 465, end of spectrum about Hδ.

7. *Discussion of Photographs.*

The following is a detailed discussion of the photographs described in Table II.

Stage 2 to Stage 4.

No 19. This photograph of Vega (fourth stage), and Arcturus (second stage), is very striking in the relative intensities of the two spectra. The red portion of the Arcturian spectrum is considerably more intense and forms the one end of a maximum which—except in the green region where the plate is not very sensitive—extends from D to about λ 454. The part of the spectrum more refrangible than that rapidly becomes less intense, until at and beyond K it is very faint. Matters are very different in the spectrum of Vega. Here the maximum radiation occurs about a third of the distance from H_δ to H_γ (λ 422) and the spectrum extends without any great falling off in intensity to H_ν, beyond that it is weaker but continues without any great decrease to twice the distance on the more refrangible side of H_ν than the latter is from K. From that point to the end the spectrum gradually declines. Whilst the maximum radiation in this spectrum has moved wholesale towards the ultra-violet, the red is relatively only about half the density of the red in the Arcturian spectrum.

No. 4. The general appearance of these two spectra leads to the conclusion that that of β Ursæ Majoris (fourth stage) is much stronger than that of α Ursæ Majoris (second stage).

A more careful examination, however, shows that whilst the detached red part of the former is only seen with difficulty, the same portion of the latter is comparatively prominent.

The maximum intensity in α is situated at about λ 450 and does not vary a great deal between there and K. After the latter point is reached, however, the fall is rather sudden, and the spectrum soon dies out. In β the maximum intensity is between H and H_ϵ, and the ultra-violet up to H_κ is fairly strong. Beyond H_κ the intensity of the spectrum drops rather suddenly, and then continues with a gradual decrease for some distance.

No. 14. There is no great difference in the lengths of these two spectra, the one of α Geminorum (fourth stage), the other α Aurigæ (second stage), but the red portion of the second stage spectrum is most decidedly more intense than that of the fourth stage, the latter, in fact, being scarcely visible at all. In α Aurigæ the maximum intensity is at about λ 454, but in α Geminorum it must be placed at or near to H_δ (λ 410).

No. 37. In the taking of this negative the spectrum of Capella (second stage) received the advantage of exposure and is consequently much stronger in the H_γ—H_β region than that of Castor (fourth

stage), and yet the latter extends as far into the ultra-violet as the former.

Furthermore, the intensity of the blue part of the spectrum of Capella rises to its maximum immediately at H_β and commences to decline towards the violet at H_γ, whereas the maximum region of Castor does not commence at once after leaving the green gap, and attains its centre at about λ 422.

It will be observed that whether we take Arcturus or Capella to represent Stage 2, the spectra of stars of higher stages have relatively longer ultra-violet and reduced red radiation. It has to be noted, however, that there are indications that Stage 2 will, as a result of further work, have to be divided, for Capella is certainly hotter than Arcturus as determined in the manner now under discussion.

Stage 4 *to Stage* 6.

No. 11. On examination of this negative it is seen that the detached red portion of the spectrum of Sirius (fourth stage) is decidedly more intense than the same portion of the Rigelian spectrum (sixth stage). In the ultra-violet, however, we find that although both stars are fairly high on the temperature curve, and, therefore, both spectra extend far into the ultra-violet, the extension of the spectrum of Rigel is more intense and greater than that of Sirius.

Stage 6 *to Stage* 9.

No. 35. By reason of its greater exposure the spectrum of Rigel (sixth stage) is generally much stronger than that of κ Orionis (ninth stage), and especially is this so in the red portions of the two spectra. This inequality notwithstanding, the spectrum of κ extends practically as far into the ultra-violet as that of Rigel.

Various Intervals.

No. 34. In α Ursæ (second stage) the red part of the spectrum is comparatively very bright, nearly as bright as the region between G and F. In γ Ursæ (sixth stage) this red portion is barely visible. Again, in the α Ursæ spectrum the maximum occurs at λ 460, and then the intensity gradually declines to K, beyond which it is very faint. The maximum intensity of the γ Ursæ spectrum is situated at about λ 422, and it extends without becoming greatly impaired to H_θ.

No. 36. In this comparison we have a very striking case. The spectrum of Capella (second stage) is compared with that of η Ursæ Majoris (eighth stage); Capella has been over-exposed, so that the red portion is abnormally intense, η Ursæ Majoris received the correct exposure, and the red part of the spectrum is rather faint.

Notwithstanding this difference the spectrum of η Ursæ extends further into the ultra-violet than does that of Capella, and not only does it extend further, but the maximum intensity is extended much further into the ultra-violet than is that of Capella, which drops off rapidly beyond K.

No. 23. In this comparison the red part of the Procyon (third stage) spectrum is much brighter than that of Alnitam (ninth stage). The intensity in the longer portion of the spectrum of Procyon rises at once to its maximum at H_β, has its centre of maximum at about λ 460, and at H_γ commences to diminish towards the violet. In the spectrum of Alnitam, however, the maximum is delayed until the region about λ 426 is reached, and is then sustained up to H_ζ, finally extending to the ultra-violet with a marked superiority, comparatively, over that of the Procyon spectrum.

Extreme Interval.

No. 33. This comparison of two type stars respectively situated near the extremities of the temperature curve is naturally one of the most striking pieces of evidence in support of this method of temperature classification. The spectrum of Alnitam (ninth stage) is nowhere so intense as the red and blue parts of the Aldebaran (second stage) spectrum, and yet it extends more than twice as far towards the ultra-violet, from H_β, as the hydrogen series, whilst the more refrangible limit of the Aldebaran spectrum only extends to K. The maximum intensity of the blue portion of the Alnitam spectrum occurs much nearer the ultra-violet than that of the Aldebaran spectrum, the latter attaining its maximum at about λ 465.

8. *Conclusions.*

It may be pointed out that the temperature classification, confirmed by this research, does not agree with that published by Sir William and Lady Huggins who, in their "Atlas of Representative Stellar Spectra" containing "a Discussion of the Evolutional Order of the Stars," place the solar stars on a higher temperature level than the white stars.

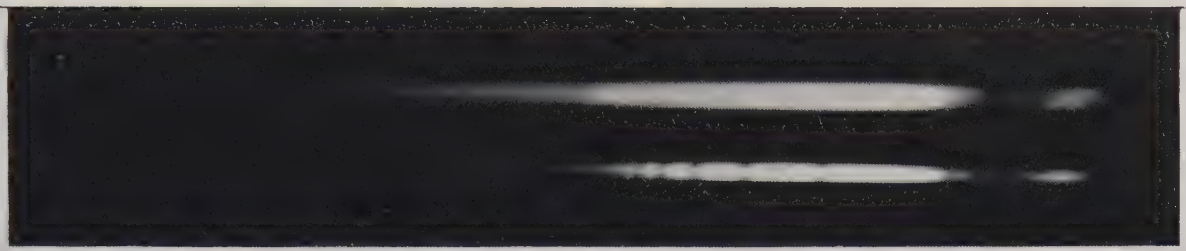
A reduction of intensity in the continuous spectrum beyond the hydrogen series to which attention has been called by more than one observer, Schumann* among others, does not affect the results which I have stated. Another paper dealing with this and similar points is in course of preparation.

The result of the research may be stated as follows:—

Taking the stars assumed to be hottest in the chemical classification, we find that in all cases the relative length of the spectrum is reduced,

* 'Smithsonian Contributions to Knowledge,' No. 1413, 1903, p. 23.

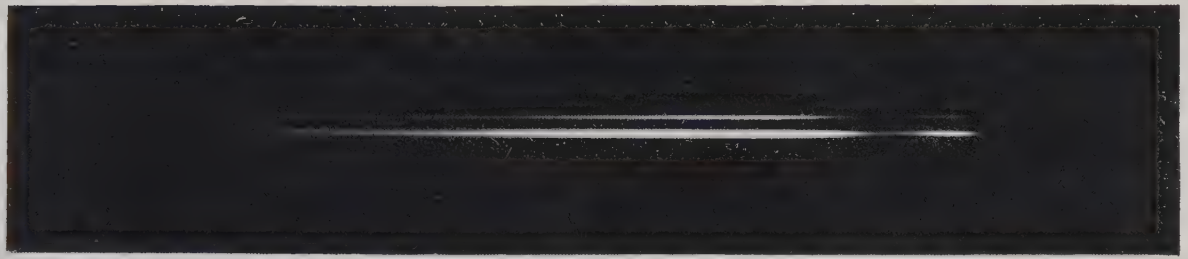
1
Stage 4
VEGA
ARCTURUS
Stage 2
2
Stage 4
CASTOR
CAPELLA
Stage 2
3
Stage 4
CASTOR
CAPELLA
Stage 2



4

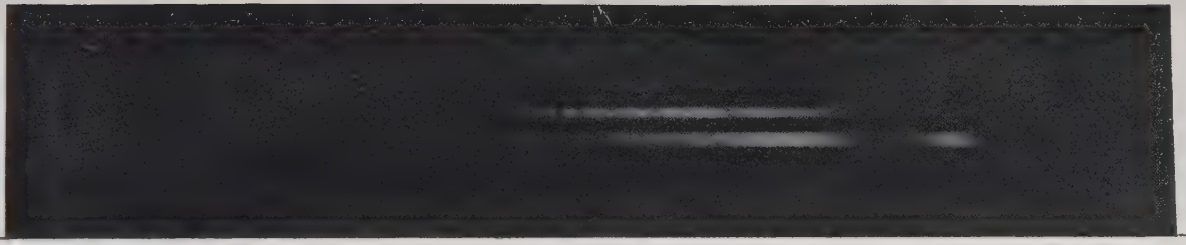
STAGE 6
RIGEL

SIRIUS
STAGE 4



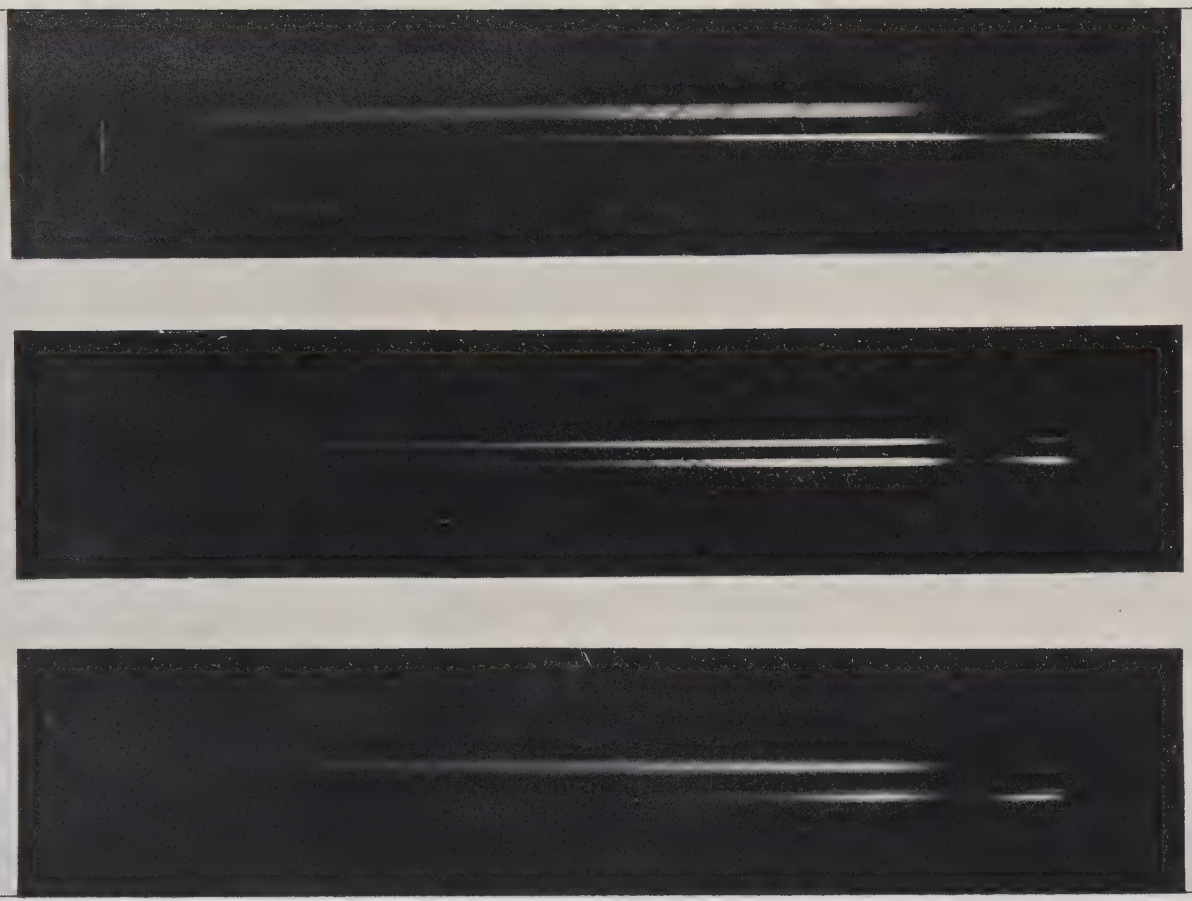
5

STAGE 9
κ ORIONIS
RIGEL
STAGE 6



6

STAGE 6
γ URSAE MAJ:
α URSAE MAJ:
STAGE 2


7
STAGE 8
η URSAE MAJ:
CAPELLA
STAGE 2
8
STAGE 9
ALNITAM
PROCYON
STAGE 3
9
STAGE 9
ALNITAM
ALDEBARAN
STAGE 2

and the relative intensity of the red is increased, as a lower temperature is reached. That is to say that where two spectra having their intensities about the region H_β — H_γ equal are compared, we find that in the cooler stars, according to the chemical classification, the emissions in the red preponderate, whilst in the hotter star the ultra-violet is more extended and intense.

My best thanks are due to Messrs. Rolston and Goodson, who took the various photographs to which I have referred, the former also helping me in the preparation of this paper, and to Mr. Wilkie for preparing the enlargements of the negatives.

9. *Description of Plates.*

No.	No. of negative.	Stars.	Stage.	Type.
		Plate [4].		
1	19	Vega	4	Sir.
		Arcturus	2	Arct.
2	14	Castor	4	Sir.
		Capella	2	Arct.
3	37	Castor	4	Sir.
		Capella	2	Arct.
		Plate [5].		
4	11	Rigel	6	Rig.
		Sirius	4	Sir.
5	35	κ Orionis.....	9	Alnit.
		Rigel	6	Rig.
6	34	γ Ursæ Maj. ..	6	Mark.
		α Ursæ Maj. ..	2	Arct.
		Plate [6].		
7	36	η Ursæ Maj. ..	8	Cruc.
		Capella.	2	Arct.
8	23	Alnitam	9	Alnit.
		Procyon	3	Proc.
9	33	Alnitam	9	Alnit.
		Aldebaran	2	Aldeb.

In producing these plates the original negatives have been enlarged about $3\frac{1}{2}$ times.

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MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

APPENDIX TO VOL. LXIV.

[*From Proceedings of the Royal Society, Vol. LXXIII.*]

With indication of the original pagination.

No. 3.

CONTENTS.

	Page
Sir N. and Dr. W. J. S. Lockyer, The Behaviour of the Short-Period Atmospheric Pressure Variation over the Earth's Surface	[36]
Professor S. Arrhenius, On the Electric Equilibrium of the Sun . .	[50]

"The Behaviour of the Short-Period Atmospheric Pressure Variation over the Earth's Surface." By Sir NORMAN LOCKYER, K.C.B., LL.D., F.R.S., and WILLIAM J. S. LOCKYER, Chief Assistant, Solar Physics Observatory, M.A. (Camb.), Ph.D. (Gött.), F.R.A.S. Received April 13,—Read April 28, 1904.

In a paper which we communicated to the Society in June, 1902,* we drew attention to the fact that in our investigation dealing with the percentage frequency of prominences and changes in atmospheric pressures, we found that the pressures in India and Cordoba behaved in an opposite manner, the short period variations of one being the inverse of those of the other; both, however, were closely associated with the prominence frequency.

In a subsequent paper† we showed that these two regions, in which these inverse pressure-variation conditions were clearly distinguishable, were, as far as had then been investigated, of considerable extent, the Indian region extending to Ceylon, Java, Mauritius and Australia, and that of Cordoba to the southern part of the United States.

The facts there collected were stated to be so suggestive that the inquiry was being continued by collecting and discussing observations made in other areas on the earth's surface, so as to note the extent of these similar pressure areas.

The present communication contains the results that have so far been obtained.

The greater portion of the facts here collected has been discussed some time, but as it was considered desirable, before communicating the present paper, to include as many regions on the earth's surface as could be obtained, a longer delay than was anticipated has taken place; even now there are many regions which we have been unable to include. The regions for which further observations are desired include the west coast of Africa, the northern part of South America, and the north-western portion of North America, and Polynesia in the South Pacific Ocean.

In our previous papers we have pointed out the advisability of dividing the year into groups of months according as the pressure is above or below the mean value for the year. In this way the high or the low pressure months can be dealt with separately, if necessary, and any excess or deficiency from a mean value exhibited in either or both of these from year to year can be closely followed.

Such a division of the year can be accurately determined for places

* 'Roy. Soc. Proc.,' vol. 70, p. 500.
† 'Roy. Soc. Proc.,' vol. 71, p. 134.

which have a regular and pronounced annual pressure variation, such as India, and where the yearly barometric range is of far greater magnitude than any other aperiodic fluctuation.

In those regions where the mean yearly curve is more misleading than otherwise, the division, according to the two seasons included in the two groups of months, April to September and October to March, is best adapted.*

The system adopted in the present investigation was to take the pressure variations over India and Cordoba as the chief types of each region, denoting those of the former by the symbol (+), and those of the latter by (−). The pressure curve of any other place was then taken and compared with each. If, for example, it was found that the curve extending over several years exhibited an excess pressure at those epochs when the Indian pressure curve was in excess, then it was classified as being similar to the Indian type and represented by a (+). If it was seen that although it was more like the Indian curve than that of Cordoba, but yet not quite the exact counterpart of India, then it was denoted by (+?). In a similar way pressure curves like Cordoba were classified as (−), and those more like Cordoba than India as (−?).

In some regions the pressure variation curves were distinctly a mixture of both the Indian and Cordoba types, and it was difficult to classify them satisfactorily by the above method. The symbol adopted for these cases was (±?). Again, there were further some curves in which even this mixed type of symbol was not sufficient to exhibit the relationship of their variations to the other curves, so a special symbol (?) denoting ambiguity was used.

In the present investigation of this similarity or dissimilarity of atmospheric pressure changes over large areas, it was found that the special types were apparent sometimes in the yearly curves, sometimes in those for one or other of the high or low pressure groups of months, or sometimes in both of these. It did not, however, appear to follow that, because the type was distinguishable in the yearly curves, it was necessarily apparent in both the curves of the high and low pressure months.

The accompanying table, although yet somewhat incomplete, gives a tabulated statement of the data employed in the present survey.

The table explains itself, but it may be remarked that in Columns 6

* To show the misleading nature of the mean annual pressure-variation curve over, for example, the British Isles, it is only necessary to plot the actual monthly values of pressure for any one year on this mean curve and draw a curved line through them, when it will be seen that there is practically no relationship whatever between the two curves. If, on the other hand, the actual monthly pressure values during any one year be plotted on the mean annual pressure-variation curve for India, the former follow very closely the swing and amplitude of the latter.

Analysis of

Country.	Station.	Type.	Remarks on type.	Period of observations.
India	Bombay	+	Chief (+) type, see Plate [8]	1860—1903
	Madras	+	.. ..	1861—1902
	Calcutta	+	.. ..	1860—1902
	Nagpur	+	.. ..	1869—1903
	Darjeeling	+	.. ..	1875—1901
Ceylon.....	Colombo	+	.. ..	1881—1900
Persia	Bushire.....	+	.. ..	1879—1887
Arabia.....	Aden	+	.. ..	1883—1899
Indian Ocean	Seychelles.....	+	.. ..	1885—1898
	Rodriguez	+ ?	.. ..	1885—1898
	Mauritius.....	+	.. ..	1875—1901
East Indies..	Batavia	+	.. ..	1866—1898
Philippines..	Manila	± ?	.. ..	1883—1901
Malay Penin.	Singapore	+	.. ..	1869—1902
Australia	Perth	+	Slight differences	1876—1900
	Adelaide	+	Remarkably pronounced, see Plate [8]	1876—1899
	Sydney	+	.. ..	1860—1899
New Zealand	Dunedin	?	Difficult to classify	1866—1898
	Auckland	?	„ „	1867—1903
Africa.....	Zanzibar (Island)....	+ ?	.. ..	1880-3—1891-7
	Durban	+	.. ..	1884—1903
	Capetown	+ ?	.. ..	1860—1899
	Cairo.....	+ ?	.. ..	1869—1898
	Alexandria	± ?	.. ..	1870—1896
	Biskra.....	± ?	.. ..	1874—1884
	Sierra Leone.....	− ?	.. ..	1876—1900
	St. Thomas (Island)..	(+ ?)	.. ..	1874—1883
	Kimberley	+ ?	.. ..	1876—1899
	St. Paul de Loando...	+ ?	.. ..	1880—1895
South America	Cordoba	−	Chief (−) type, see Plate [8]	1873—1902
	Tugumen	−	Distinctly like Cordoba ..	1885—1897
	Goya	−	Exactly like Cordoba	1877—1897
	Santiago	−	.. ..	1874—1884
	Rio de Janeiro	− ?	.. ..	1860—1899
West Indies..	Jamaica	− ?	.. ..	1866—1900
	Barbadoes	?	.. ..	1865—1900

Pressure Types.

Months in which types are most conspicuous.		Source of data.	General remarks.
Apr.—Sept.	Low press.	Indian Monthly Weather Reviews	Type equally prominent in curve for year.
,,	,,	,, ,,	,, ,,
,,	,,	,, ,,	,, ,,
..	..	,, ,,	Yearly curve only examined.
..	..	,, ,,	,, ,,
Apr.—Sept.	Low press.	,, ,,	Type equally prominent in curve for year.
Oct.—Mar.	High press.	,, ,,	Record very short.
Apr.—Sept.	Low press.	,, ,,	Equally prominent in yearly and Oct.—Mar. curves.
..	..	Mauritius Met. Obsns.	Yearly curve alone examined.
..	..	,, ,, ...	Short and uncertain record. Yearly curve examined.
May—Oct.	High press.	,, ,, ...	Prominent in yearly curve.
June—Oct.	,,	Meteorological Office	,, ,,
..	..	Report of Philippine Commission	
..	..	Met. Obsns. at Straits Settlements	,, ,,
Apr.—Sept.	High press.	Met. Obsns. at Perth and district	
,,	,,	Met. Obsns. at Adelaide.....	Very prominent in yearly curve.
,,	,,	Met. Obsns. in New South Wales	,, ,,
..	..	New Zealand Statistics (Met.)	1877 pulse absent.
..	..	Met. of New Zealand	
Nov.—Apr.	Low press.	Indian Monthly Weather Reviews	Record very broken and short.
Oct.—Mar.	,,	Report of Govt. Astronomer, Natal	
Apr.—Sept.	High press.	Meteorological Office	Broken record, 1871—1877.
,,	Low press.	Met. Report of Abassia Obsy., Cairo	
,,	,,	Met. Zeitschrift, 1897	
Oct. Feb.	High press.	Kong. Sv. Vet. Ak. Handlingar, vol. 29, No. 3	Record too short.
..	..	Army Medical Dept. Reports	Yearly curve alone examined.
Nov.—May	Low press.	Lisbon Met. Obsns.	Record too short.
..	..	.. .. ..	Yearly curve alone examined.
..	..	Supplement to Annals of Lisbon Observatory and Loanda Met. Obsns.	,, ,,
Apr.—Sept.	High press.	Anales de l'Oficina Met. Argentina, vol. xiii	
,,	,,	Anales de l'Oficina Met. Argentina	Broken record.
,,	,,	,, ,,	Continuous good record.
May—Oct.	,,	Kong Sv. Vet. Ak. Handlingar, vol. 29, No. 3	
May—Sept.	,,	Meteorological Office	
..	..	Army Medical Dept. Reports	Yearly curve alone examined. Two short breaks in record.
..	..	,, ,,	,, ,,

Analysis of Pressure

Country.	Station.	Type.	Remarks on type.	Period of observations.
North America	Jacksonville	−	Some slight differences	1873—1899
	Mobile	−	,, ,,	1873—1899
	Pensacola	−	,, ,,	1880—1899
	Nashville	− ?	Marked differences	1873—1899
	San Diego	−	Slight differences	1873—1899
	St. Louis	− ?	Marked differences	1873—1899
	Bismarck	− ?	,, ,,	1875—1899
	Kansas City	± ?	.. ..	1890—1899
	Boise	− ?	.. ..	1878—1890
	Salt Lake City	− ?	Slight differences	1874—1899
	Santa Fé	−	Close resemblance	1873—1899
	Denver	− ?	.. ..	1863—1899
	Portland	± ?	Equally like both types	1873—1899
	Galveston	−	Some slight differences	1873—1899
	Alpena	± ?	Difficult to determine	1873—1899
	Buffalo	± ?	,, ,,	1873—1899
	Pikes Peak	± ?	,, ,,	1874—1887
	Ft. St. Michaels (Alaska)	+ ?	.. ..	1874—1884
Atlantic Ocean	Bermuda	−	Undoubtedly this type	1866—1899
Canada	Toronto	± ?	.. ..	1874—1890
	Fort Garry (Manitoba)	± ?	.. ..	1874—1891
Nova Scotia	Sydney	− ?	See Plate [8]	1874—1898
Sandwich Isles	Honolulu	−	1877 Indian pulse present	1873 –1901
Tahiti	Papeete	± ?	Like India, one year in advance	1876—1891
Greenland	Jacobshavn	?	.. ..	1873—1897
	Godthaab	+ ?	Very like Jacobshavn, see Plate [7]	1873—1895
Iceland	Stykkisholm	+ ?	Very slight differences, 1877 present, see Plate [7]	1874—1901
	Berufjord	+ ?	Very slight differences, 1877 present, see Plate [8]	1874—1901
Europe	Tromso	± ?	.. ..	1874—1898
	Vardo	− ?	.. ..	1870—1898
	Aalesund	+ ?	.. ..	1861—1898
	Stornoway	± ?	1877 pulse absent	1863—1903
	Aberdeen	± ?	Very slight differences, 1877 absent	1869—1899
	Armagh	± ?	,, ,,	1869—1903
	Stonyhurst	± ?	.. ..	1885—1902
	Valencia	± ?	See Plate [7]	1863—1899
	Palermo	± ?	.. ..	1874—1884
	Madrid	± ?	Remarkable likeness to (−) at times, see Plate [7]	1860—1899
	Gibraltar	− ?	Like Oct.—Apr., Azores	1864—1900
	Lisbon	− ?	.. ..	1860—1896
	Vienna	± ?	See Plate [7]	1860—1901
	Constantinople	+ ?	.. ..	1874—1884

Types—*continued.*

Months in which types are most conspicuous.		Source of data.	General remarks.
Nov.—Feb.	High press.	Report of Chief of Weather Bureau, U.S.A.	
Oct.—Mar.	,,	,, ,,	
Nov.—Mar.	,,	,, ,,	
Sept.—Feb.	,,	,, ,,	
Nov.—Apr.	,,	,, ,,	
(Mar.—Aug.)	(Low press.)	,, ,,	
Apr.—Sept.	Low press.	,, ,,	
,,	,,	,, ,,	Short record.
Oct.—Mar.	High press.	,, ,,	,,
May—Oct.	Low press.	,, ,,	
Dec.—May	,,	,, ,,	Record broken, 1882—1885.
June—Nov.	High press.	,, ,,	
,,	,,	,, ,,	Yearly mean curve alone examined.
Oct.—Mar.	High press.	,, ,,	
,,	,,	,, ,,	,, ,,
,,	,,	,, ,,	,, ,,
,,	,,	,, ,,	Short record.
,,	,,	Kong. Sv. Vet. Ak. Handlingar, vol. 29, No. 3	Yearly curve alone examined. Broken record.
Dec.—Mar.	High press.	Army Medical Dept. Reports	Record somewhat broken.
,,	,,	Report of Met. Service of Dom. of Canada	Yearly curve alone examined.
,,	,,	,, ,,	,, ,,
Aug.—Nov.	High press.	,, ,,	Record broken after 1891.
Aug.—Feb.	Low press.	Met. Obsns., Honolulu	Record twice broken.
,,	,,	Met., Zeitschrift, 1892	Yearly mean curve examined.
,,	,,	Danish Met. Aarbog	Record broken, 1883—1887.
Oct.—Mar.	Low press.	,, ,,	,, 1874—1875.
Apr.—Sept.	High press.	,, ,,	
,,	,,	,, ,,	
Sept.—Mar.	Low press.	Met. Aarbog Norsk	
,,	,,	,, ,,	
Apr.—July	High press.	,, ,,	
,,	,,	MSS. Met. Office Records	Yearly curve alone examined.
Apr.—Sept.	High press.	,, ,,	
,,	,,	,, ,,	
,,	,,	Results of met. and mag. observations, Stonyhurst	,, ,,
Apr.—Sept.	High press.	MSS. Met. Office Records	
,,	,,	Kong. Sv. Vet. Ak. Handlingar, vol. 29, No. 3	
Mar.—Aug.	Low press.	Madrid Met. Obsns.....	
,,	,,	Army Medical Dept. Reports.	,, ,,
,,	,,	Lisbon Met. Obsns.....	
,,	,,	Denkschriften Kaiserlichen Ak. de Wissenschaften	
Apr.—Sept.	Low press.	Kong. Sv. Vet. Ak. Handlingar, vol. 29, No. 3.	Short record of definite type.

Analysis of Pressure

Country.	Station.	Type.	Remarks on type.	Period of observations.
North Atlantic	Azores	− ?	Remarkable, undoubted (−), see Plates [7] and [8]	1874—1903
	Las Palmas	− ?	.. ..	1882—1892
Russia	St. Petersburg	− ?	.. ..	1870—1899
	Moscow	− ?	.. ..	1870—1899
	Tarchankut	?	Difficult to classify	1874—1884
	Lugansk	− ?	.. ..	1872—1899
	Orenbourg	− ?	.. ..	1870—1899
	Catherinbourg	− ?	.. ..	1870—1899
	Arkangel	− ?	.. ..	1871—1899
Siberia	Tomsk	− ?	.. ..	1874—1899
	Barnaoul	− ?	.. ..	1870—1899
	Nertchinsk	− ?	.. ..	1870—1899
China	Pekin	?	.. ..	1874—1881
	Zi-ka-wei	+ ?	.. ..	1874—1884
	Hong-Kong (Island)	−	Exactly like Cordoba	1884—1903
Japan	Tokio	± ?	.. ..	1873—1895
	Kioto	± ?	.. ..	1883—1899

and 7 are given the groups of months (whether high or low pressure months) in each case for which the pressure curves examined afforded the greatest resemblance to the types which form the basis of the classification. In cases in which the curves of the mean yearly values alone have been utilised, these columns have been left blank and reference made in the column headed "General Remarks."

Although the above classification gives a very fair idea on the whole of the types of pressure variations from one region to another, minor peculiarities have been met with which have tended to add a certain amount of difficulty.

These remarks apply principally to places in the more northern latitudes.

Thus, for instance, Greenland and Iceland have been classified as of the (+?) type, the British Isles, Germany, and Spain of the (±?) type, and the Azores of the (−?) type. From a glance at the accompanying plate (Plate [7]), which shows the relation to each other of some of the pressures over these areas, the changes from a (−?) to a (+?) type can be observed.

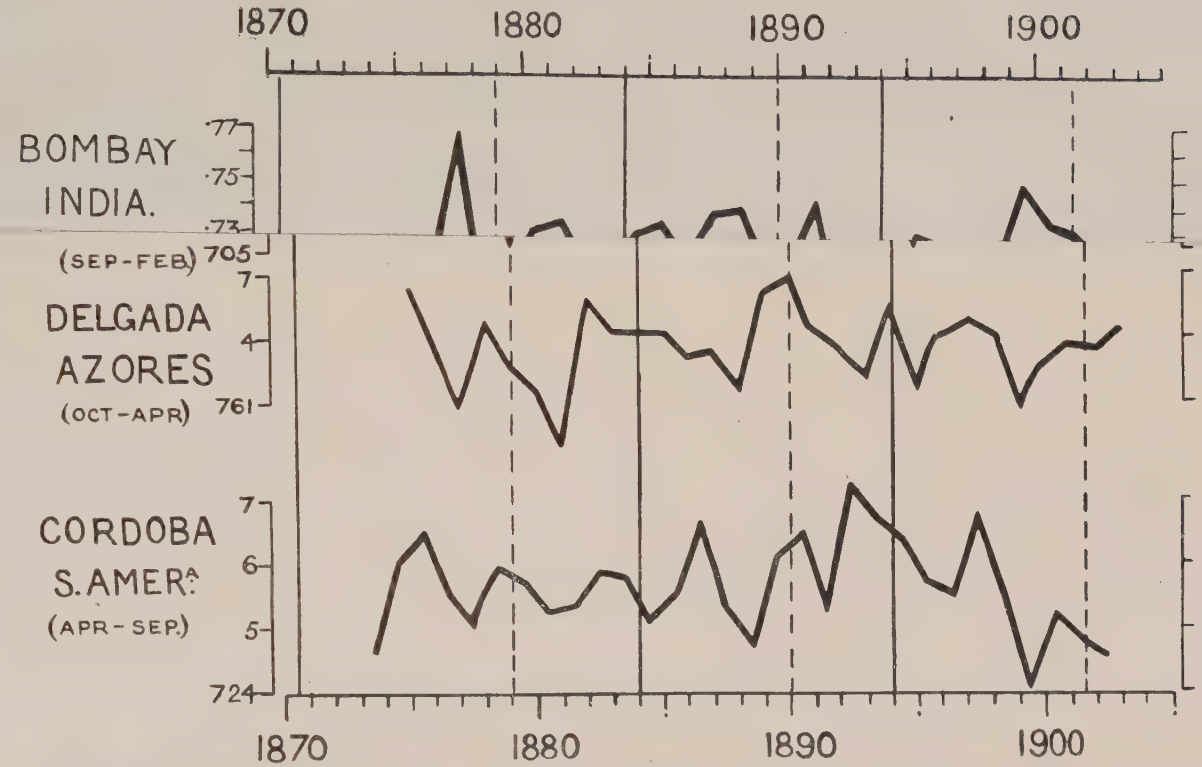

PLATE [7].—Shewing the Relationship between the Short Period Pressure Variations for places in Western Europe, and the two Main Types of Pressure Variations, namely: India (+) and Cordoba (−). This Plate should be studied in relation to the map in fig. 1. *Note.*—The continuous and broken vertical lines denote the epochs of sunspot maxima and minima as determined from the mean daily areas of both hemispheres of the sun.

Types—*continued.*

Months in which types are most conspicuous.		Source of data.	General remarks.
Oct.—Apr.	Low press.	Annales de l'Obsy. do Infante D. Luiz	Prominent in yearly curve.
..	..	Résumé de las Obs. Met. de Provinces (Spanish)	1886 no record.
..	..	Annales de l'Obsy. Cent. Phys. de Russe	Yearly curve alone examined.
Sept.—Feb.	High press.	,, ,,	
..	..	Kong. Sv. Vet. Ak. Handlingar, vol. 29, No. 3	
Oct.—Mar.	High press.	Meteorological Office	
..	..	Annales de l'Obsy. Cent. Phys. de Russe	Break in record 1875—1887. Yearly curve alone examined.
..	..	,, ,,	Yearly curve alone examined.
Jan.—June	High press.	Meteorological Office	
Oct.—Mar.	,,	,, ,,	Prominent in yearly curve.
,,	,,	,, ,,	,, ,,
Apr.—Sept.	Low press.	,, ,,	
..	..	Annales de l'Obs. Cent. Phys. de Russe	
Oct.—Mar.	High press.	Kong. Sv. Vet. Ak. Handlingar, vol. 29, No. 3	Short record. Prominent in yearly curve.
Apr.—Sept.	Low press.	Met. Zeitschrift, 1886, and Observations made at Hong-Kong Observatory	Visible in yearly curve.
,,	,,	Met. Zeitschrift, 1899.....	
..	..	Report of Cent. Met. Obsy. of Japan.	All the curves for the half-yearly and yearly values show similar variations.

It will be seen that although practically the same groups of months have been taken in each case, pressure in excess of the mean value in Greenland or Iceland corresponds to a deficiency of pressure over the area covered by Great Britain, Austria and Spain, the curves being in the main the reverse of each other. Again, the pressure curve for the Azores follows more nearly the (−) type, as will be seen by comparing it with the Cordoba curve, but it has a certain similarity to those of Madrid, Vienna, etc., to which it must therefore be closely connected.

While the western portion of Europe is of this (± ?) type, the eastern portion gradually assumes the (− ?) type, and this region extends not only probably to Norway and Sweden, but right across European and Asiatic Russia. The European Russian type of curve has an undoubted similarity to those of more Western Europe, but there are variations which indicate that the type is more like that of Cordoba than India.

Again, another region in which rather mixed types of pressures are

met with is that of Eastern and North-eastern Canada. Curiously enough Prince Edward Island and Sydney (Nova Scotia) correspond very closely to the (−) type, if allowance be made for the differences about the year 1877.

The inverted curve for the latter with the Adelaide (Australia) pressure curve for comparison is shown in an accompanying plate (Plate [8]).

In addition to illustrating this reversal between Adelaide (+) and Sydney (Nova Scotia) (−?), this plate shows also, to serve as examples, curves for two other sets of reverse pressure conditions. Thus, Bombay (+) is compared with the Cordoba (−) pressure curve (inverted), and is an example of the adopted types of pressure variation. Iceland is compared with that of the Azores (inverted), and shows the reverse conditions that prevail between a (+?) type and a (−?) type.

A fact to which attention was very often drawn in attempting to classify the pressure curves was that some curves after following very closely for many years the Cordoba (−) or Indian (+) type of pressure, as the case may be, would revert back to the opposite type for a period of years. Thus to take the case of one station alone, namely, Sydney (Nova Scotia) as an instance, the pressure curve follows very closely that of India from 1875—1882, after which up to 1890 it has a very close resemblance to the Cordoba type. The behaviour of this Sydney (Nova Scotia) pressure curve can be compared with the Adelaide (Australia) curve in Plate [8], but it must be noticed that the former has here been *inverted*.

There is another important fact which this study has brought to light and which plays most probably an important *rôle* with regard to the pressure variations at places which exhibit a mixed type of pressure. The earth's surface as has been shown may be divided mainly into two regions, one portion showing excess pressures at certain epochs, while the other shows deficient pressure at the same epochs. If the former region exhibits a greater excess than usual (as an example, the Indian region in 1877), then the region over which this type of pressure occurs may probably be more extensive, and the boundary dividing the two chief types of pressure will necessarily be pushed away from this region. Stations, therefore, that were just on the fringe of this boundary may at these epochs become enveloped in this more extensive high-pressure area, and will exhibit the Indian type of pressure variation.

Should the Cordoba region become more extensive than usual owing to a similar cause, then the border stations will assume the Cordoba type of pressure variation. It is not proposed to enter here into detail on this point, as the subject requires very close examination, but mention may be made of the very great area which

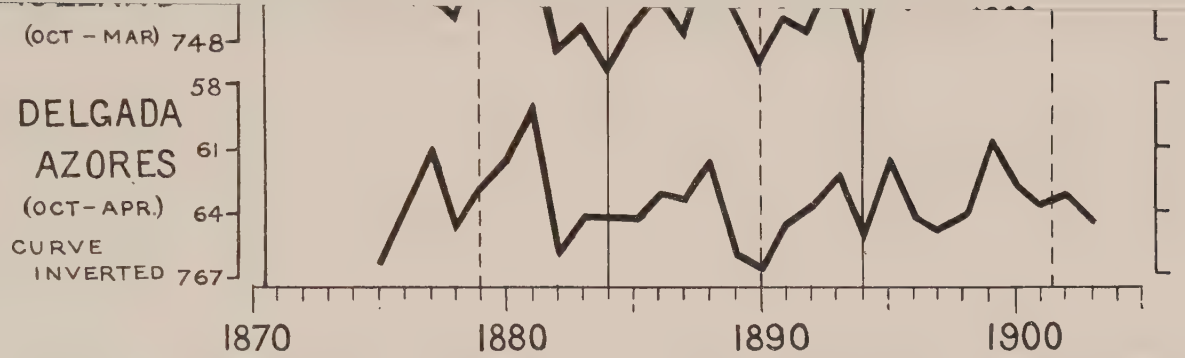

PLATE [8].—Three pairs of Curves to illustrate Reverse Pressure Conditions at stations widely separated geographically, such as India and Cordoba (S. America), Adelaide (S. Australia) and Sydney (Nova Scotia), and at two stations near each other, as Berufjord (Iceland) and Delgada (Azores). In each case the second curve has been reversed. *Note.*—Vertical lines same as in Plate [7].

was covered by the continuous excessive high pressure that prevailed over the Indian region from the end of 1876 to about the middle of 1878.

On fig. 1 is given a map of the world on which are marked the types of pressure variations in each region which is included in this barometric survey.

An attempt has been made by means of a neutral line to show approximately the mean lines of separation of these two chief pressure types, although it must be remembered that this line is liable to a probable small oscillation about its mean position.

As far as can at present be determined, one line commencing to the west of Alaska, separating this region from Siberia, passes easterly along about the 60° parallel of latitude and runs in a south-easterly direction between South-west Greenland and North-east Canada. It then crosses the North Atlantic, passing to the north of the Azores, and skirts the south-western portion of Portugal. It then strikes down towards the Equator, cutting North-west Africa, as far as can be judged from the scant pressure values available, through the middle of the Sahara. It leaves Africa near the Gold Coast, passes into the South Atlantic, where it cannot be traced further owing to lack of observations in this southern ocean.

The other boundary or neutral line passes to the north-east of Greenland and north of Iceland, crosses the southern portion of Norway and Sweden, and traverses Southern European Russia. It then takes a course somewhat more easterly, skirting the northern part of the Caspian Sea and Turkestan, passes between Tibet and Mongolia, and through China. It then leaves the Continent a little to the south of the Yellow Sea, and passes into the North Pacific Ocean. Here its path cannot be traced, but it evidently passes well to the east of the Philippine Islands and Solomon Islands, takes a new south-westerly course, skirting the eastern side of Australia and passing between Tasmania and New Zealand. Its track is then again lost in the Southern Pacific Ocean.

Although too much weight must not at present be given to the positions of these neutral lines throughout their whole length, it is interesting to note that they are fairly symmetrical to one another, although no attempt has been made to make them so.

Both lines apparently cross the equator at about antipodal points, and both appear to have a similar trend in northern and southern latitudes.

We seem then to be in presence of a general law relating to the pressures which occur simultaneously in two different regions of the globe, separated and defined more or less by a neutral line, this neutral line forming a fulcrum about which see-saws of pressure from one region to another take place. Special cases of such reverse pressure variations have been previously detected.

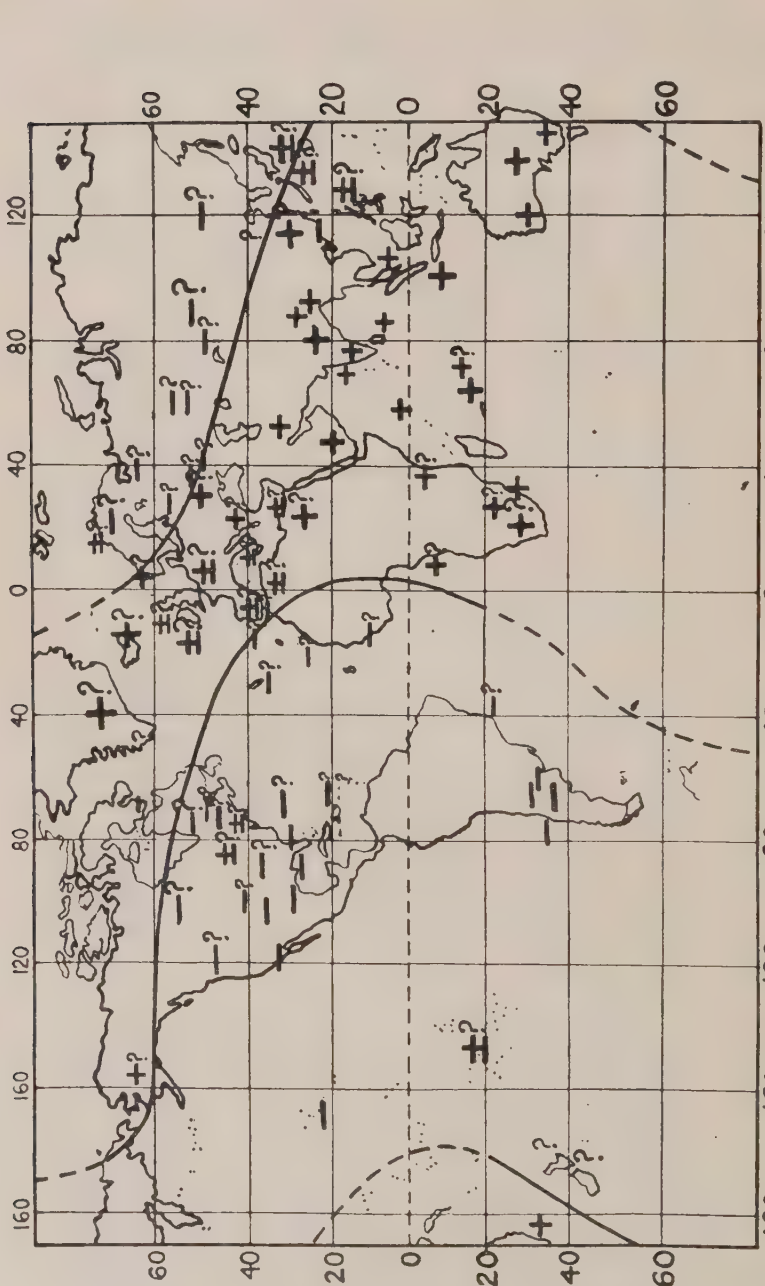

FIG. 1.—Illustrating the Distribution of the two Main Types of Atmospheric Pressure Variations. The symbols signify:—(+) like India, (+ ?) more like India than Cordoba, (−) like Cordoba, (− ?) more like Cordoba than India, (± ?) mixture of India and Cordoba, (?), difficult to classify.

Thus as long ago as 1879 Blanford,* from a discussion of the secular variations of barometric pressure over the wide area covering Siberia, Indo-Malaysia and Australia, pointed out that there existed a kind of long-period see-saw of a character that, while the pressure at the tropical stations was low, that in Siberia was high, and *vice versâ*. This fact, it will be seen, is quite in harmony with the pressure-type distribution, as shown in the accompanying map (fig. 1).

Hildebrandsson† has discussed the relation between the pressure variations of numerous places mainly situated in the chief centres of action of the atmosphere widely distributed on the earth's surface for the period 1874—1884. In this valuable communication, some of the chief results which he was led to deduce were that there were several regions which exhibited opposite types of pressure variations.

The following places are those to which he calls attention, and for comparison we give the types in brackets which have been allotted according to the method adopted in the present paper; where no type is added the region has not been examined :—

The Azores (− ?) and Iceland (+ ?); Siberia (− ?) and Alaska (+ ?), especially in winter; Tahiti (± ?) and Tierra del Fuego; India (+) and Siberia (− ?); Greenland (+ ?) and Key West (Florida) (−); Buenos-Ayres (− ?) and Sydney (Australia) (+).

It is interesting to note that these results agree well in the main with the present distribution of the regions which have been examined.

Again Hann‡ has recently drawn attention to the fact that there exists a see-saw between the Azores and Iceland, and he showed that in 80 per cent. of cases the largest positive pressure variations at Stykkisholm (Iceland), corresponded to negative pressure variations at Ponta Delgada (Azores), and that the largest negative pressure variations at Stykkisholm were in 87 per cent. of cases positive varia tions at Ponta Delgada.

This result obtained from the observations extending from 1846—1900 endorses Hildebrandsson's previous conclusion deduced from observations over the period 1874—1884, and confirms the position of the neutral line shown on fig. 1, dividing the two large types of pressure areas.

Quite recently Professor Bigelow§ has published a map of the world on which he has indicated the distribution of the pressure types according as they follow the Indian (or direct type, as he calls it) or the Cordoba (indirect) pressure variations.

Professor Bigelow has also found that there are many regions in

* 'Report of the Meteorology of India in 1878,' pp. 2—35.

† "Quelques Recherches sur les Centres d'Action de l'Atmosphère," 'Kongl. Svenska Velenskaps-Akad. Handlingar,' vol. 29, No. 3.

‡ 'Kaiserliche Akademie der Wiss. in Wien,' January 7, 1904.

§ 'Monthly Weather Review,' p. 509, November, 1903.

which it is very difficult to say exactly which type is followed, and as he says there may be "differences of opinion as to the assignment of some of these curves, but the reader can make any different arrangement that he prefers."

In most of the main features, however, his map suggests a somewhat similar distribution of these pressure types to that given here. Thus, he finds that "the region around the Indian Ocean gives direct synchronism, South America and North America give inverse synchronism, while Europe and Siberia give an indifferent type. Greenland and Iceland seem to have direct type like the Indian Ocean . . . .

"The eastern hemisphere tends to direct synchronism, except in Europe and Russia where the indifferent type prevails, and the western hemisphere to the inverse type."

It may be further pointed out that regions which are the reverse of one another as regards these secular pressure variations should very probably experience opposite kinds of abnormal weather, while those over which the same type of pressure variation exists should have weather of an abnormal but similar nature.

That this is inclined to be so as regards the latter statement has been recently* very forcibly pointed out by Sir John Eliot with respect to the Indian area. He writes:—

"The drought of 1895—1902 was a more or less general meteorological feature of the whole area, including Abyssinia, East and South Africa, Afghanistan, India, probably Tibet, and the greater part or whole of Australia."

The whole of this region, as will be seen from the accompanying map (fig. 1), is embraced by the (+) type of pressure.

In the light, therefore, of the existence of these large regions of opposite pressure types, it is vital in the interest of long-period forecasting that observations from all portions of the globe should be included in any discussion.

Several years ago Eliot† drew attention to these oscillations of pressure of long period, other than the diurnal and annual oscillations in India. In this important memoir he pointed out that "they are directly related to the largest and most important features of the weather in India, viz., the character and distribution of the precipitation of rain and snow in the Indian monsoon area."

There is reason, therefore, to believe that this short period pressure variation will in the future be of considerable assistance in helping

* 'Broad Views,' p. 193; 'The Meteorology of the Empire during the Unique Period 1892—1902,' by Sir John Eliot, K.C.I.E., F.R.S.

† "A Preliminary Discussion of certain Oscillatory Changes of Pressure of Long Period and of Short Period in India," 'Indian Met. Memoirs,' vol. 6, part 2, 1895.

meteorologists to form a more definite idea of the prospects of approaching seasons.

We wish to express our thanks to Dr. W. N. Shaw, F.R.S., who has kindly assisted the work by permitting us to utilise the valuable collection of pressure data deposited in the archives of the Meteorological Office.

We also owe a debt of gratitude to Messrs. W. Moss and T. F. Connolly, who have shown great zeal in completing the necessary computations and drawing the numerous curves which were required for the different stations that have been investigated.

"On the Electric Equilibrium of the Sun." By SVANTE ARRHENIUS. Communicated by Sir WILLIAM HUGGINS, Pres. R.S. Received and read June 2, 1904.

In recent years many attempts have been made to apply the pressure of radiation, that is a consequence of the theories of Maxwell and Bartoli, to the explanation of cosmical phenomena. Especially the enigma of the nature of comets' tails has been elucidated from this new point of view.

In a memoir presented to the Swedish Academy of Sciences in 1899, I pointed out that several electric and magnetic phenomena, especially auroras and magnetic storms, might also be connected with the pressure of radiation. C. T. R. Wilson found that the negative ions condense vapours more easily than do positive ions. Without doubt the gases in the atmosphere of the sun are practically ionised by the ultra-violet radiation. Therefore we have to suppose, that among the little drops formed by condensation in the sun's atmosphere far more are negatively charged than are positively charged. As these drops are driven away by the pressure of radiation they charge with negative electricity the atmospheres of celestial bodies, *e.g.*, the earth, which they meet, till the charge is so great that discharges occur, and cathode rays are formed, which carry the charge back to the universe.

A calculation of the speed, with which these particles move through space, will not be without interest. Suppose first, for simplicity, that the pressure of radiation is double that of the weight of the particles in the neighbourhood of the sun. It is not difficult to calculate, that in this case the time, necessary for the particle's passage from the surface of the sun to the earth, amounts to 68·7 hours. The specific weight is supposed to be that of water.

Now, after Schwarzschild's calculations, a perfectly reflecting drop

will be driven away with the greatest force from the sun if its circumference is just as great as the wave-length of the radiation. The wave-length of the maximal radiation of the sun is about 0·5 μ. Therefore the optimal dimension for a drop, that is driven away by the pressure of radiation, will be about 0·06 μ. If we suppose a specific weight of the drop like that of water, the repulsive force for a perfectly reflecting drop amounts to about ten times its weight. For a perfectly black drop it is half as great. Now, most drops are neither perfectly reflecting nor perfectly black. Most fluids absorb nearly completely the non-luminous radiation, and reflect a part of the other. An appreciation of these two factors leads to the estimation that the effect for the translucent fluids will be about half as great as for a perfectly black body, *i.e.*, about 2·5 times greater than the gravity against the sun. Such a particle will move away from the sun with 1·5 times greater speed than that calculated above, *i.e.*, it will reach the earth in about 46 hours.

Of course, there may be represented speeds that are more than the double this for drops of low specific weight (compounds of carbon and hydrogen). On the other hand, the speed may be extremely little (or negative), for drops of high specific weight (*e.g.*, gold). This will also be the case for great or very small drops, as Schwarzschild has shown.

These figures have recently acquired a great interest through the discussion by Ellis, Maunder, and Riccò of the connection between sunspots and magnetic storms. Riccò had already, in 1892, stated that in six cases of very strong magnetic storms, these appeared in mean 45·5 hours after the passage of a great sunspot over the central meridian of the sun. In one case the difference of time was only 20 hours.

From the researches of Ellis and Maunder it appears that the magnetic storms *commence* in mean 26 hours after the great groups of sunspots, which probably caused them, had passed the central meridian of the sun. Riccò applies a correction to these figures. He says that in mean the great magnetic storms, quoted by Ellis and Maunder, lasted for 33 hours, and therefore it is natural to assume that the maximum of the magnetic storm, which will probably fall near its middle, arrives 16·5 hours after its commencement. It will, therefore, be nearly true that the maximum of the magnetic storms observed by Ellis, came $26 + 16{\cdot}5 = 42{\cdot}5$ hours after the passage of the corresponding spot through the central meridian of the sun. The figure very nearly coincides with those of Riccò and also with that calculated above. Riccò also makes the observation that the velocity of the small particles, which in my opinion cause the auroras and the magnetic storms, is of the same order of magnitude as the observed velocity with which the cause of these perturbations moves from the sun.

If the sun only emitted negatively electrified particles on all sides, it would soon assume so great an electric charge of positive sign, that the electric forces would hold the negative particles back in the neighbourhood of the sun. There must, therefore, be some cause that carries back as much negative electricity to the sun as it loses through the emission of negative particles. In supposing the least negative charge to be the same as the positive one of a hydrogen atom, weighing 8×10^{-25} gramme, it may be calculated that the force with which this is drawn back to the sun by a potential slope of 3000 volts per cm., amounts to 23·2 dynes. A drop of radius 0·08 μ, of the specific weight of water, has the weight 59×10^{-10} dyne at the surface of the sun. Its repulsion by the pressure of radiation is about 2·5 times greater, 148×10^{-10} dyne. The electric attraction is therefore only about the fourth part of the total force by which the drop is driven away from the sun; therefore its speed is only three-fourths of that calculated before. It is evident that if the electric charge of the sun, or rather of its upper atmosphere, is much greater (about four times) than that supposed, no negatively charged particles can be emitted from the sun. On the other hand, if the sun's charge is less, the particles will move with a speed that is nearly independent of the magnitude of the charge. Probably the charge of the sun in times of great emission, *i.e.*, at sun-spot maxima, will be of this order of magnitude, and in times of sun-spot minima somewhat less.

The charged particles are driven out to all sides from the sun. It might, perhaps, be expected that they would lose their electric charge under the influence of the strong ultra-violet radiation from the sun. But the circumstances must be other for these small particles than for great pieces that are examined in our laboratories. Otherwise it would be impossible to conceive that drops are condensed at all on the negatively charged electrons under the influence of ultra-violet light.*

But if many drops agglomerate together, the potential increases and greater pieces are formed, which can lose their charge gradually. According to the experiments of Elster and Geitel, and Lenard, these charged bodies part slowly with their negative charge in the form of electrons that traverse space.

The path of these electrons is now influenced by the strongly positively charged suns. Their paths become by this influence curved, and they describe hyperbolas round the suns. If their perihelial distance is less than the sun's radius, they fall down on the sun, and diminish its positive charge.

If we now suppose the electric charge of the sun to be just as great

* As the first drops contain only one elementary charge of electricity, they would lose their whole charge at once at a discharge. Perhaps this circumstance causes the difference for elementary and great charges.

as assumed above, we find that electrons moving with the velocity of light are caught by the sun, if the asymptote of their hyperbolic path is less distant from the sun than 2420 times the mean distance of the earth from the sun (or one twenty-fourth of a light-year). This limit distance is inversely proportional to the velocity of the electrons, and nearly proportional to the square-root of the charge of the sun. As now, according to the researches of Lenard, the electrons from a negatively electrified body possess a much less velocity than light, this distance is really much greater than that just calculated.

If, for instance, the velocity of the electrons is the thirtieth part of that of light, a number that is in good agreement with Lenard's measurements, all electrons from space which came along a path that is less distant than 1·25 light-year from the sun, will be caught by the sun. Of course the electrons move with different velocity, so that the said distance may only be regarded as a mean, or as representing the order of magnitude.

Now our nearest star (α Centauri) is distant from us by about 4 light-years, and other stars lie within less than 10 light-years. Thus it is evident that the negative electrons, which are sent off from aggregates of negatively charged drops (these aggregates are probably identical with what we call cosmic dust or meteorites), can in general not pass by many suns without being caught by them. And on the other hand the suns recover in mean from space as much negative electricity as they lose. The electric charges of the suns are in this respect very effective regulators. If the charge is quadrupled the mean distance of the caught electrons is doubled, or, in other words, as they are uniformly disseminated in space, their quantity is quadrupled. Therefore the supply of negative electricity to the suns is proportional to their defect thereof.

From these considerations we see that a very effective balance of gains and losses of negative electricity is maintained. Evidently this balance depends upon the supposition that for the particles that drive away from the sun, other forces than the electric, viz., the pressure of radiation, are preponderating, whilst for the negative electrons caught by the sun, other forces than the electric are wholly insignificant compared with these.

If one supposed, as some authors do, that the negative electricity was carried away from the sun by means of cathode rays, an effective circulation like that described above would be wholly impossible.

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MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

APPENDIX TO VOL. LXIV.

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CONTENTS.

Page

Sir N. Lockyer, On the Relation between the Spectra of Sunspots and Stars. [55]

Sir N. Lockyer and Dr. W. J. S. Lockyer, A Probable Cause of the Yearly Variation of Magnetic Storms and Auroræ . . . . . [57]

"On the Relation between the Spectra of Sunspots and Stars." By Sir Norman Lockyer, K.C.B., LL.D., F.R.S. Received June 8,—Read June 16, 1904.

As the period throughout which the observations of widened lines have been made at South Kensington now includes two maxima and three minima epochs of solar activity, it has seemed desirable to discuss the results obtained, taking into account the chemical origins of the lines affected in passing from the photosphere to the sunspot nuclei. This is going on, but in anticipation of its publication, I desire to direct attention to one of the conclusions arrived at in its bearing upon the question of the temperature conditions of the Arcturian and lower type stars, which formed part of the subject of a recent paper.*

Since 1894, when the last discussion of the widened line results was published,† nearly 10,500 observations of lines in sunspot spectra have been made at South Kensington. An analysis of these lines, in respect to their origins, shows that *the elements chiefly affected during the period* 1892—1903, *inclusive, were Vanadium and Titanium.*

The great importance of Vanadium and Titanium in sunspot spectra has also been demonstrated by Father Cortie during his observations in the B—D region at Stonyhurst.‡

It was foreshadowed in a previous paper on the chemical classification of the stars§ that it seemed probable that, as the result of further work, the "genera" then proposed might have to be split up into "species." During the more recent research mentioned above the temperature classification was tested by comparing the relative intensities of the red and ultra-violet ends of the spectra of stars, situated on various horizons of the temperature curve, including Capella and Arcturus, which, according to the original general classification, belong to the same type, viz., "Arcturian." It was found that the spectrum of Capella extended on an average about 70 tenth-metres further into the ultra-violet than that of Arcturus, whilst the red portion of the spectrum is certainly stronger in the latter. That is to say, *the general temperature of Arcturus is probably appreciably lower than that of Capella.*

The next step was to see if chemical change accompanied this reduction of temperature, and if so, whether the change was in any way related to the change from the photosphere to the sunspot spectrum.

* 'Roy. Soc. Proc.,' vol. 73, pp. 227—238, 1904.

† 'Roy. Soc. Proc.,' vol. 57, p. 199, 1894.

‡ 'Monthly Notices (R.A.S.),' vol. 63, No. 8, pp. 479–480, June, 1903.

§ 'Roy. Soc. Proc.,' vol. 65, p. 191, 1899.

In comparing, for this purpose, the spectra taken with the 6-inch Henry prismatic camera it was noticed that certain lines were relatively intensified in passing from the spectrum of Capella to that of Arcturus.

Similar comparisons of the Fraunhoferic spectrum with the spectra of Capella and Arcturus respectively were next made. This work led to the following conclusions :—(1) That the line absorptions of Capella and the sun are practically identical; (2) that although, speaking generally, the same lines occur in the spectra of the sun and Arcturus, yet in the latter many lines are relatively more intense than in the former. Moreover, in the great majority of such cases *the lines so intensified are probably due to Vanadium and Titanium.*

Thus we see that whilst the temperature classification mentioned above certainly places Arcturus on a lower temperature level than Capella and, therefore, the sun, the evidence obtained from a study of the line absorptions of Arcturus and of sunspots indicates very clearly that the temperature of the Arcturian absorbing atmosphere is about the same as that of the sunspot nuclei during the above-mentioned period.

This conclusion justifies the ideas formulated by De la Rue, Stewart, and Loewy that the spots are produced by the downrush of cooler material.

In a recent publication,* which has been received here since the above-mentioned comparisons were completed, Professor Hale suggests that because the lines which are widened in sunspots appear as strong dark lines in Piscian stars, the effect may be produced because sunspots are more numerous in such stars. From the evidence adduced above it seems a far more probable explanation to suppose that these lines are intensified in sunspots, and strengthened in those stars which have been placed on lower temperature levels than the sun, because the general temperature conditions are similar. That is to say, the fall of temperature experienced by the metallic vapours in passing from the photosphere to the spot nucleus is of the same order as that to which an absorbing atmosphere is subjected in passing from the temperature conditions of Capella or the sun to that of Arcturus or the lower temperature stars.

* "The Spectra of Stars of Secchi's Fourth Type" ('The Decennial Publications,' Chicago University, 1903).

"A Probable Cause of the Yearly Variation of Magnetic Storms and Auroræ." By Sir Norman Lockyer, K.C.B., LL.D., F.R.S., and William J. S. Lockyer, M.A. (Camb.), Ph.D. (Gött.), F.R.A.S., Chief Assistant Solar Physics Observatory. Received June 3,—Read June 16, 1904.

The ordinary meteorological elements, such as atmospheric pressure, temperature, etc., have a yearly change satisfactorily explained as due to changes of the position of the earth's axis in relation to the sun, or, in other words, the variation of the sun's declination. There are, however, other phenomena, such as magnetic disturbances and auroræ, which have been explained differently.

Thus, in regard to this seasonal variation Mr. Ellis* has written, "The related physical circumstance is that at the equinoxes, when disturbance is more frequent, the whole surface of the earth comes under the influence of the sun, whilst at the solstices, when magnetic disturbance is less frequent, a portion of the surface remains for a considerable period in shadow."

The object of the present communication is to put forward another possible cause.

It has been previously pointed out† that a very close relationship exists between the epochs of occurrence of prominences in the polar regions of the sun and Ellis's "great" magnetic disturbances. This synchronism showed that either the polar prominences themselves, or the disturbances thus indicated in these polar regions, were the origin of these "great" magnetic storms, or that they were caused by a more general stirring-up of a greater extent in latitude of the solar atmosphere.

A further investigation‡ indicated, however, that in all probability it was either the actual polar prominences themselves, or the activity in the solar polar regions, that initiated these magnetic disturbances, for it was there pointed out that the presence of polar prominence activity-tracks synchronised with the appearances of large "polar" coronal streamers. Here we have an indication of a local cause and effect.

It will be gathered, then, that, even as regards terrestrial magnetic phenomena, considerable importance must be attached to action taking place in the regions about the solar poles.

Since the axis on which the sun rotates is inclined to the plane of the ecliptic, there will be times throughout the course of a year when the solar polar regions will be exposed most and least to the earth.

* 'Monthly Notices,' vol. 61, p. 540.

† 'Roy. Soc. Proc.,' vol. 71, p. 244; also 'Monthly Notices, R.A.S.,' vol. 63, Appendix I, p. 6.

‡ 'Monthly Notices, R.A.S.,' vol. 63, p. 481.

It should be expected, then, that if the polar regions of the sun have any action, as above suggested, the effects of the action on the earth should vary according to the positions of the solar poles relative to the earth.

The actual inclination of the sun's axis being 82° 45′, and the longitude of the ascending node being 74° 25′, or the tilt of the axis being in the direction of about 19 hours in right ascension, it follows that, in each year, the south pole of the sun is most turned towards the earth in the beginning of March (about the 6th), and the north pole most towards the earth in the beginning of September (about the 5th). At the two intermediate epochs, in June (about 5th) and December (about 6th), neither pole is turned towards or away from the earth, but occupies an intermediate position. Hence we see that the equinoxes occur in the same months as those in which one or other of the solar poles is turned towards the earth, while the neutral positions of the solar poles in relation to the earth occur in the same months as the solstices.

The accompanying diagram shows graphically the relation between

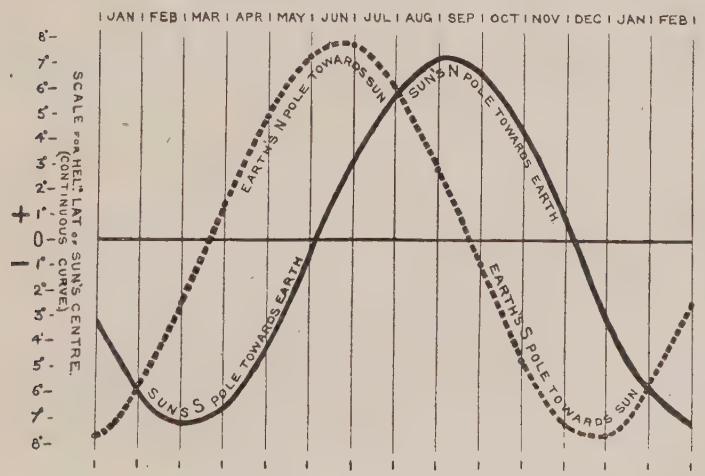
I JAN I FEB I MAR I APR I MAY I JUN I JUL I AUG I SEP I OCT I NOV I DEC I JAN I FEB I
SCALE FOR HEL. LAT. OF SUN'S CENTRE. (CONTINUOUS CURVE)
SCALE OF SUN'S DECLINATION. (DOTTED CURVE)
+20°
+15°
+10°
+5°
0
-5°
-10°
-15°
-20°
EARTH'S N POLE TOWARDS SUN
SUN'S N POLE TOWARDS EARTH
SUN'S S POLE TOWARDS EARTH
EARTH'S S POLE TOWARDS SUN

FIG. 1.—Curves showing the relation between the change of declination of the Sun (broken curve) and the positions of the Sun's north and south poles with regard to the earth (continuous curve) throughout a year.

the two curves representing the variation of the sun's declination and the change of the latitude of the sun's centre or the variation of the amount of the tilt of the solar poles, in relation to the earth throughout a year.

It will be seen that the curve representing the tilt of the solar axis

is nearly (a little less than) a quarter of a phase in advance of that indicating the declination change, so that the maximum or minimum point of the latter curve is only slightly in advance of the *mean* points respectively of the former curve.

If, therefore, these solar polar regions are capable of disturbing the magnetic and electric conditions on the earth, as has been above suggested, then, when they are most directed to her at the equinoxes, the greatest effects during a year should be recorded, and when they are least directed the effects should be at a minimum.

It will not be necessary here to refer at any great length to statistics relating to the annual inequality of magnetic disturbances and auroræ, for these have been very efficiently worked out and the results published by Mr. William Ellis.*

Mr. Ellis has shown that the curves of frequency of magnetic disturbances at Greenwich and Paris are very similar, "showing maxima at or near the equinoxes, and minima at or near the solstices." These also, he further points out, are similar, with regard to the epochs of maxima, to the curve representing the frequency of the aurora at London. In the case of auroræ observed in Edinburgh, North-East Scotland and in different regions in Scandinavia, the months in which the greatest frequency is recorded are September and October (perhaps more generally October) and March and April (perhaps more generally March). Mr. Ellis is inclined to the opinion that there is a small tendency for the autumn maximum to become a little later (from September to October) and the spring maximum somewhat earlier (from April to March) as higher latitudes are approached.

Further, he points out that in more northern latitudes the mid-winter minimum of lower latitudes appears to diminish and eventually disappears, so that the curve of frequency of the aurora between October and March is practically flat with a small intermediate maximum about January. This change in form of the frequency curve in regions in close proximity to the magnetic pole, and where the conditions of day and night are so different, is of great interest, but requires careful consideration before it can be regarded as representing real auroral changes.

The accompanying curves, fig. 2, illustrate the relation throughout a year between the positions of the earth's poles with reference to the sun; the positions of the sun's poles as regards the earth; the frequency of magnetic storms at Greenwich and Paris; and lastly, the frequency of the aurora as observed at Edinburgh and at stations in Scandinavia below latitude 65° N. The first two curves are those that have already been given in fig. 1, but plotted differently. They have here been so arranged that the maxima points represent the epochs when each of the poles is most inclined to the sun or earth as the case

* 'Monthly Notices, R.A.S.,' vol. 60 p. 142; vol. 61, p. 537; vol. 64, p. 229.

may be. Both the magnetic and auroral curves represent four of the set of curves which Mr. Ellis* has recently published.

It need scarcely be pointed out that the low minima of the auroral

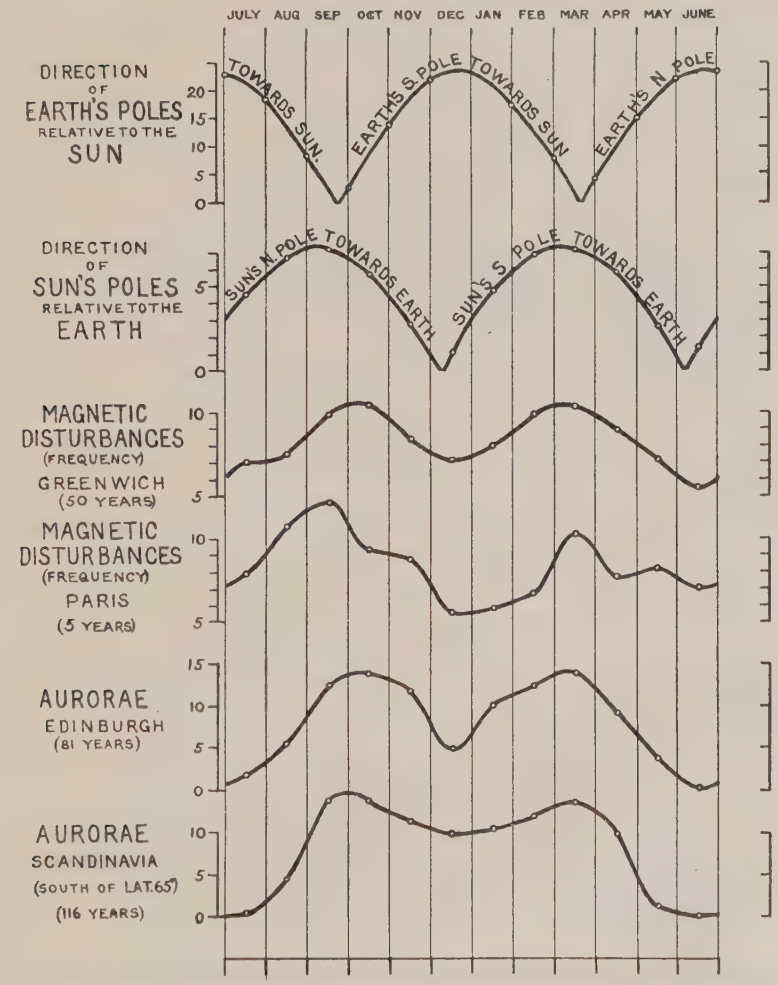
JULY AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUNE
DIRECTION OF EARTH'S POLES RELATIVE TO THE SUN
TOWARDS SUN
EARTH'S S. POLE TOWARDS SUN
EARTH'S N. POLE
DIRECTION OF SUN'S POLES RELATIVE TO THE EARTH
SUN'S N. POLE TOWARDS EARTH
SUN'S S. POLE TOWARDS EARTH
MAGNETIC DISTURBANCES (FREQUENCY) GREENWICH (50 YEARS)
MAGNETIC DISTURBANCES (FREQUENCY) PARIS (5 YEARS)
AURORAE EDINBURGH (81 YEARS)
AURORAE SCANDINAVIA (SOUTH OF LAT. 65°) (116 YEARS)

FIG. 2.—Curves showing the relationship between the positions of the Sun's north and south poles with regard to the earth and the frequency of magnetic disturbances and auroræ throughout a year.

curves during the summer months are due in great part to the shortness of the nights, and therefore to the restriction of the time available for aurora observations.

The coincidence in time between the epochs of the maxima of the

* 'Monthly Notices, R.A.S.,' vol. 64, p. 229.

frequency of magnetic disturbances and auroræ, and those of the greatest inclination towards the earth of the north and south solar polar regions is clearly indicated.

It is interesting to inquire in what way this yearly inequality of terrestrial magnetic phenomena is influenced when the sun's polar regions are, for different groups of years, in an undisturbed and disturbed condition.

It would be expected that the oscillation of more disturbed solar polar regions towards and away from the earth would tend to *increase the difference* between the frequency of magnetic disturbance at the equinoxes and solstices, while this difference for those years when the less disturbed solar polar regions are in action, should be somewhat *reduced*. That this is actually the case is brought out by the figures which Mr. Ellis has given in the publication of which mention has already been made.

Since the greatest magnetic storms are closely associated in point of time with prominence disturbances in the polar regions of the sun, to make the necessary comparison, therefore, the years in which "great" magnetic storms occurred should be grouped together and the yearly inequality determined, and another group of years in which "great" magnetic storms were less frequent formed and the yearly inequality also determined. Fortunately a computation already made can be utilised for this comparison, for Mr. Ellis has determined the number of days of greater frequency (near sunspot maximum), and lesser frequency (near sunspot minimum), of magnetic disturbance, both groups practically including the conditions required. Thus he has formed groups of the years 1848—51, 1858—61, 1869—72, 1882—85, 1892—95, which include, at any rate for the last three groups, the years where prominences were in high latitudes and another series of groups of years, 1854—57, 1865—68, 1876—79, 1887—90, which are years when prominences were less frequent in these regions.*

The interesting conclusion to which Mr. Ellis arrived was that "the excess of the equinoctial frequency over the solstitial frequency is greater, the greater the degree of disturbance."

This result thus helps to endorse the suggestion made in a previous

* The fact that continuous observation of solar prominences was only commenced in 1870 accounts for our lack of knowledge of the frequency of this class of phenomena before that date. Since, however, during the last three sunspot cycles it has been observed that polar prominences are most frequent just a little after a sunspot minimum and up to and at the epoch of the following sunspot maximum, it may be concluded that their appearance previous to the year 1870 occurred at the same times in relation to the sunspot cycle. Ellis's groups of years previous to that date, namely, 1848—51 and 1858—61, may on these grounds be classed as years in which polar prominences were present, whilst the groups 1854—57 and 1865—68 may be taken as epochs when polar prominences were not so frequent.

paragraph that the greater the disturbed solar polar regions, the greater the difference between the magnetic frequency at the equinoxes and solstices.

Conclusions.

The conclusions arrived at in the above paper may be briefly stated as follows :—

1. The seasonal variation in the frequency of magnetic storms and auroræ depends on the positions of the sun's axis in relation to the earth.

2. The epochs of the greatest inclinations of the sun's axis towards or away from the earth, or in other words the greatest exposure of the N. or S. solar polar regions to the earth during a year, correspond to those of greatest magnetic and auroral frequency.

3. The epochs (groups of years), when the solar polar regions are most disturbed, synchronise with those when the excess of the equinoctial over the solstitial frequency of magnetic storms is greatest.

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LIST OF ADDITIONS

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An asterisk (*) indicates that the work is an excerpt.

Abbadia, Observatoire:

Observations faites au cercle méridien en 1901 . . . publiées par M. Verschaffel.
(*Observatory.*) 4to. Paris, 1903

Adams (Walter S.):

—— : *Some results with the Bruce Spectrograph.
(*Author.*) 8vo. Chicago, 1902

—— : *The orbit of the spectroscopic binary η Orionis.
(*Author.*) 8vo. Chicago, 1903

Adelaide, Government Observatory:

Meteorological Observations made at the Adelaide Observatory and other places in South Australia and the Northern Territory during the year 1899, under the direction of Sir Charles Todd.
(*Observatory.*) fol. Adelaide, 1902

Albrecht (Th.):

——: *Ueber die Wahl der Stationen für den internationalen Polhöhendienst.
(*Author.*) 4to. Berlin, 1896

——: Neue Bestimmung des geographischen Längenunterschiedes Potsdam–Greenwich.
(*Author.*) 8vo. Berlin, 1904

Alessio (Alberto):

Determinazione speditiva della longitudine con osservazioni del cratere lunare "Mösting A."
(*Author.*) 8vo. Città di Castello, 1903

Algiers, Observatoire:

—— : Carte photographique du Ciel. Zone $-1°$, $+1°$, $+3°$. (26 charts.)
(*French Minister of Public Instruction.*)

Algiers, Observatoire—*continued.*

——: Catalogue photographique du Ciel. Coordonnées rectilignes. Introduction par Ch. Trépied. Tome 5, fasc. 1; 6, fasc. 1; 7, fasc. 1.
(*French Minister of Public Instruction.*) 4to. Paris, 1903

Algué (José):

Ground temperature observations at Manila, 1896–1902.
(*Philippine Weather Bureau.*) 8vo. Manila, 1902

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*Miscellaneous scientific papers; new series, No. 11–17. By F. L. O. Wadsworth, Director.
(*Observatory.*) 8vo. 1903

American Academy of Arts and Sciences: *see* Boston.

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(*Editors.*) 4to. Baltimore, 1903–1904

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(*Editors.*) 8vo. New Haven, 1903–1904

Amsterdam, Koninklijke Akademie van Wetenschappen:

——: Verhandelingen (Eerste Sectie), Deel 8, pt. 3–5.
(*Academy.*) 8vo. Amsterdam, 1903
Pt. 5. C. Easton, La Distribution de la Lumière Galactique.

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(*Academy.*) 8vo. Amsterdam, 1902–1903

——: Proceedings of the section of Sciences, vol. 5.
(*Academy.*) 8vo. Amsterdam, 1902–1903

——: Jaarboek, 1902.
(*Academy.*) 8vo. Amsterdam, 1903

Angelitti (Filippo):

Osservazioni di Distanze Zenitali fatte . . . nel R. Osservatorio di Capodimonte, 1893–94.
(*Author.*) 4to. Palermo, 1902

Astronomical and Astrophysical Society of America:

Second, Third, and Fourth Meetings, 1900–1902.
(*Society.*) 8vo. 1900–1903

Astronomical Journal. Founded by B. A. Gould [edited by S. C. Chandler]. Vol. 23, 24 (No. 539–562).
(*Editor.*) 4to. Boston, 1903–1904

Astronomische Mittheilungen. Gegründet von Rudolf Wolf: herausgegeben von A. Wolfer. No. 94.
(*Editor.*) 8vo. Zürich, 1903

Astronomische Nachrichten: Begründet von H. C. Schumacher: herausgegeben von H. Kreutz. Band 162–165 (No. 3876–3955).
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(*Editor.*) 4to. Kiel, 1904

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